Twin Ports Climate Conversations

DEPARTMENT OF NATURAL RESOURCES

1854 TREATY AUTHORITY
• BOIS FORTE
• GRAND PORTAGE

Sea Grant
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MINNESOTA POLLUTION CONTROL AGENCY

Natural Resources Research Institute
University of Minnesota Duluth
Driven to Discover

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

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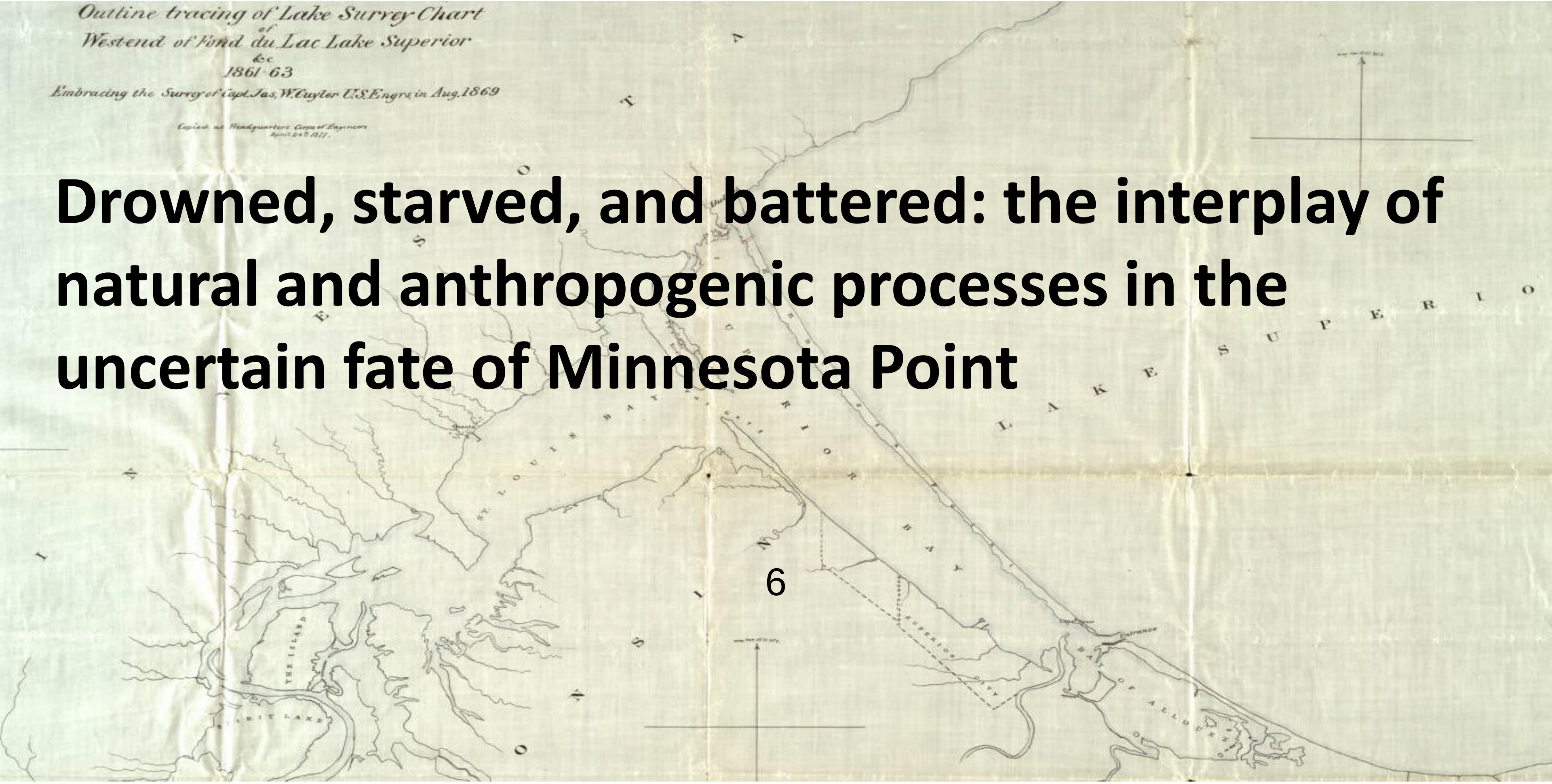

Drowned, starved, and battered: the interplay of natural and anthropogenic processes in the uncertain fate of Minnesota Point

6

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UMD University of Minnesota Duluth
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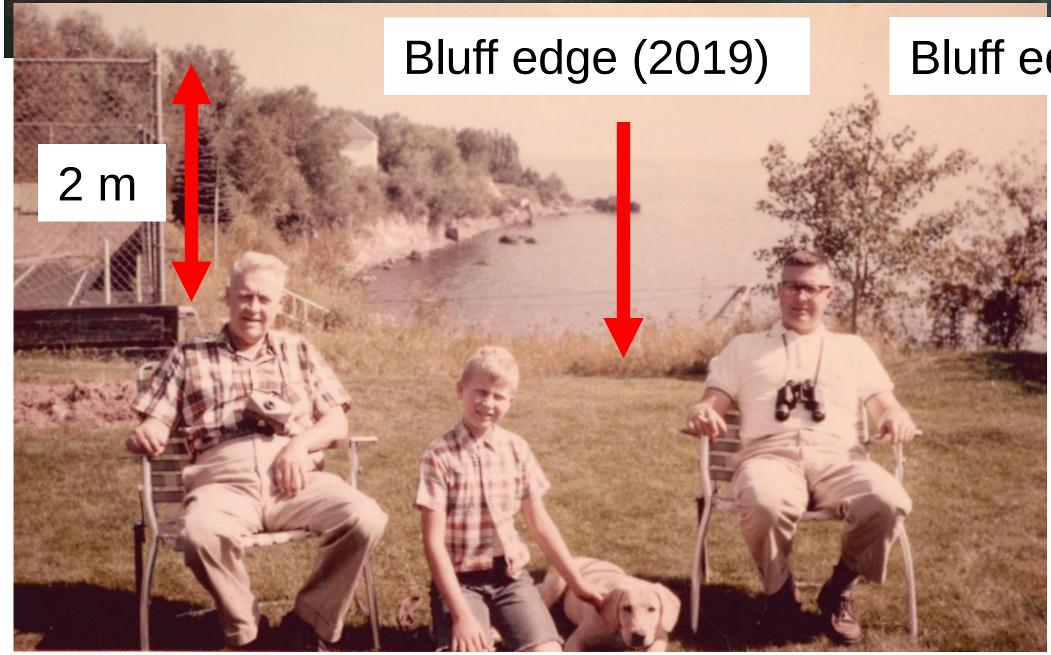
Motivation

Photo in next image

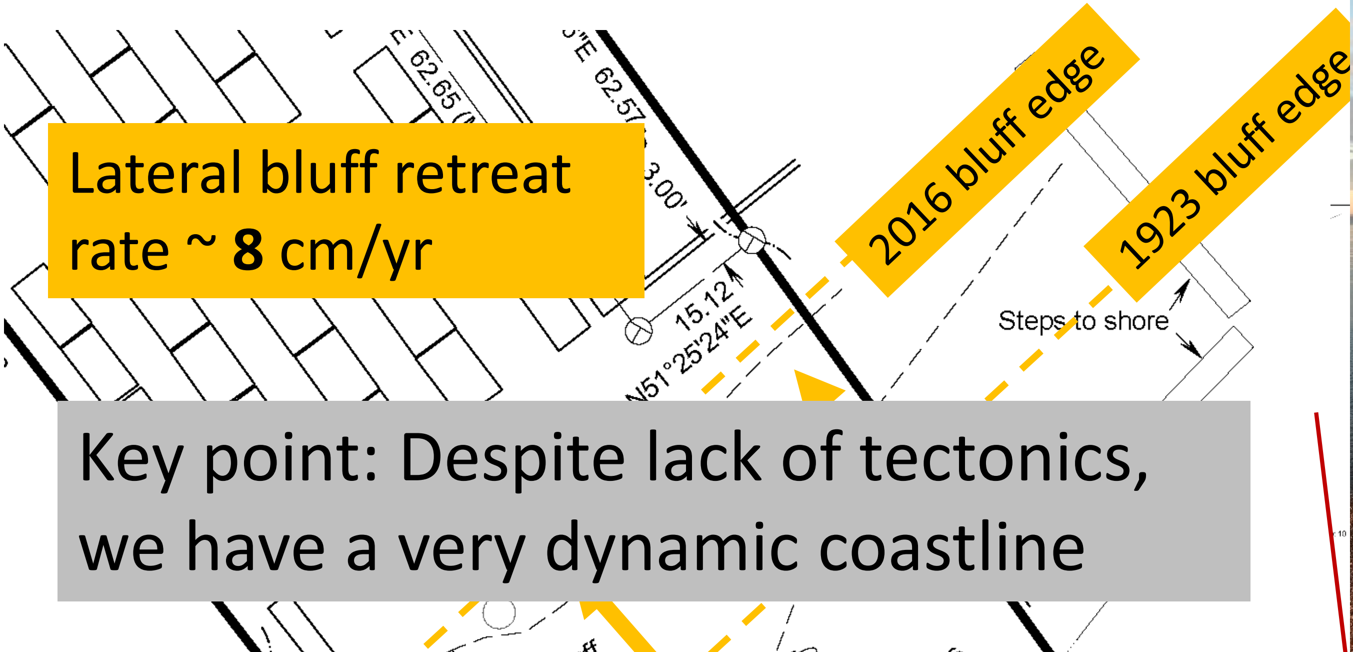
Childhood / current home

Bluff edge (2019)

Bluff edge (1967)



Lateral bluff retreat rate ~ **8** cm/yr



Key point: Despite lack of tectonics, we have a very dynamic coastline

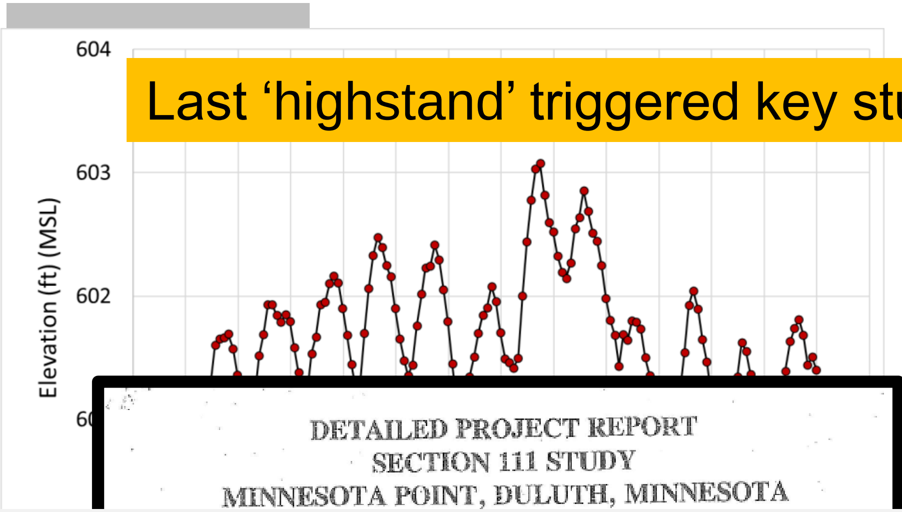
Fate of eroded material?

Goals of this talk:

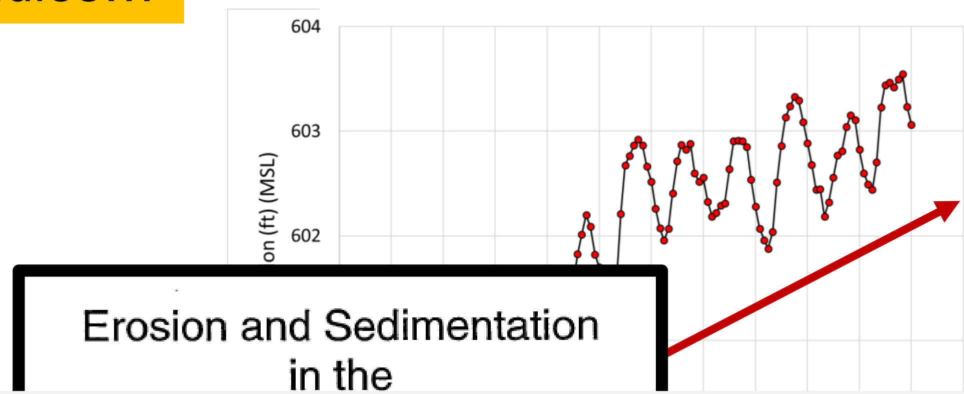
- Highlight recent research by myself, students, & collaborators
- **Synthesize** our work with previous research
    - Assemble the pieces of the puzzle…
- Present a long-term, **source-to-sink** model framework for erosion, transport, and deposition (**sediment pathways**) in the Duluth coastal region
- Use model framework to discuss the effects of anthropogenic **infrastructure** (‘**starved**’) and **climate change** (‘**drowned** and **battered**’)

Expenditure of tens of millions of taxpayer dollars requires sound understanding of sediment pathways and rates

Last ‘highstand’ triggered key studies…



Lake Superior level
(2009 – 2019)

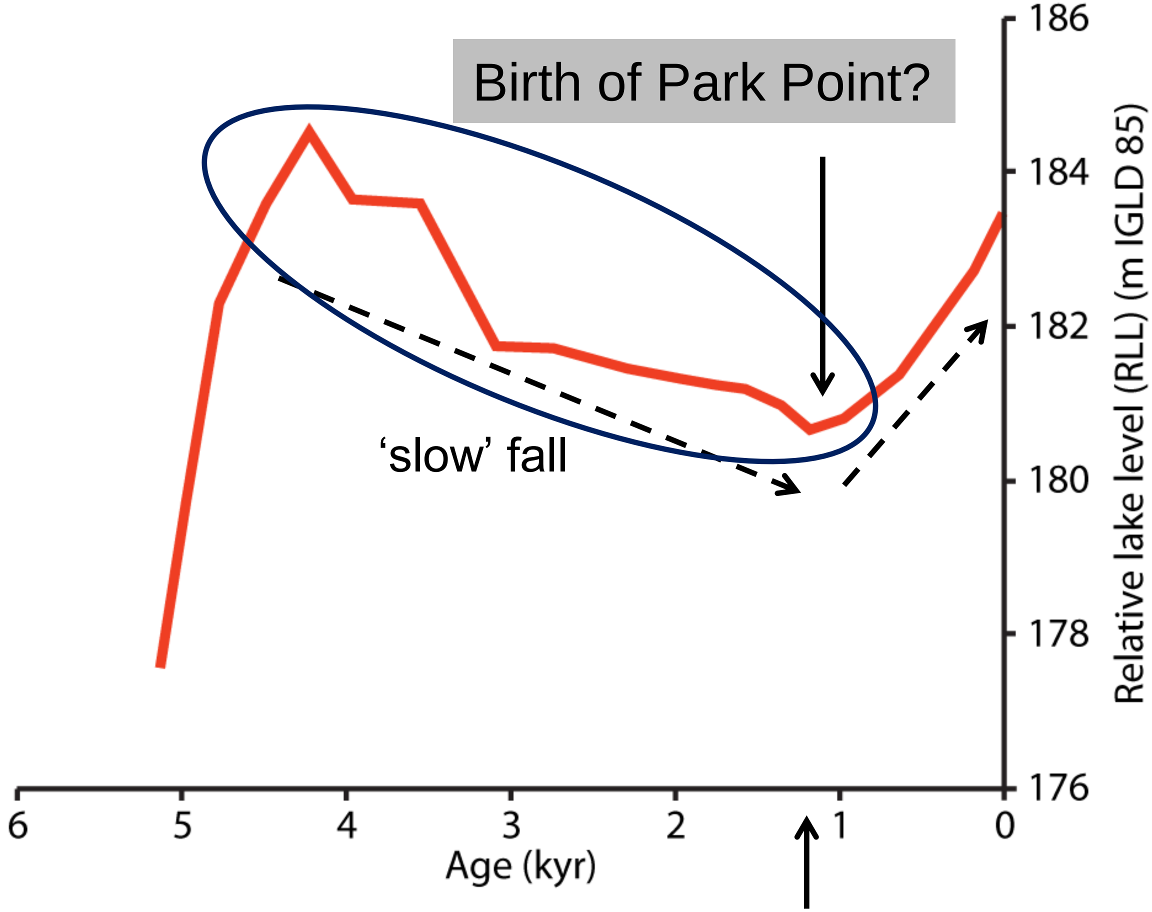


My take-home message:

- Coastal erosion in western Lake Superior is a persistent ‘problem’ over the last **1200** +/- years
- Driver for erosion is long-term lake-level **rise** (**2** - **3** mm/yr)
- Long-term rise and associated erosion ‘problem’ gave us Minnesota Point…
- …and the Duluth-Superior Harbor

Long-term lake level change in Duluth area

Lake-level curve by Andy Breckenridge (UWS; unpublished; pers. comm.) based on earlier work by Johnston et al. (2012) and Yu et al. (2013)



Slowly **falling** lake level from about 4500 yr BP – 1200 yr BP

Change in outlet of Lake Superior @ ~ 1200 yr BP triggers **rise** in lake level

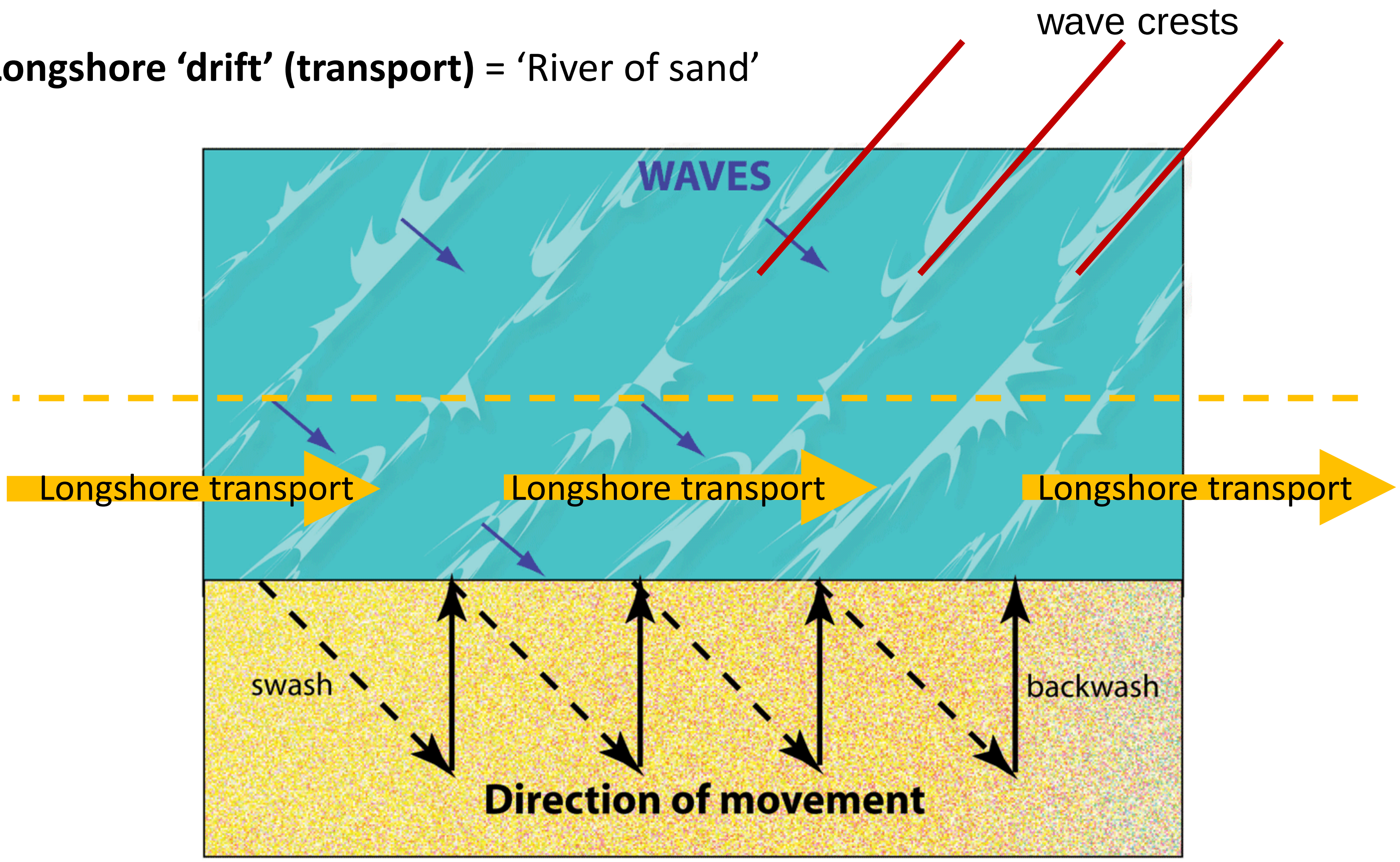
Rise rate ~ 2.5 – 3.0 mm/a in Duluth = FAST (geologically speaking)

~ 1200 yr BP (+/- geologic slop)

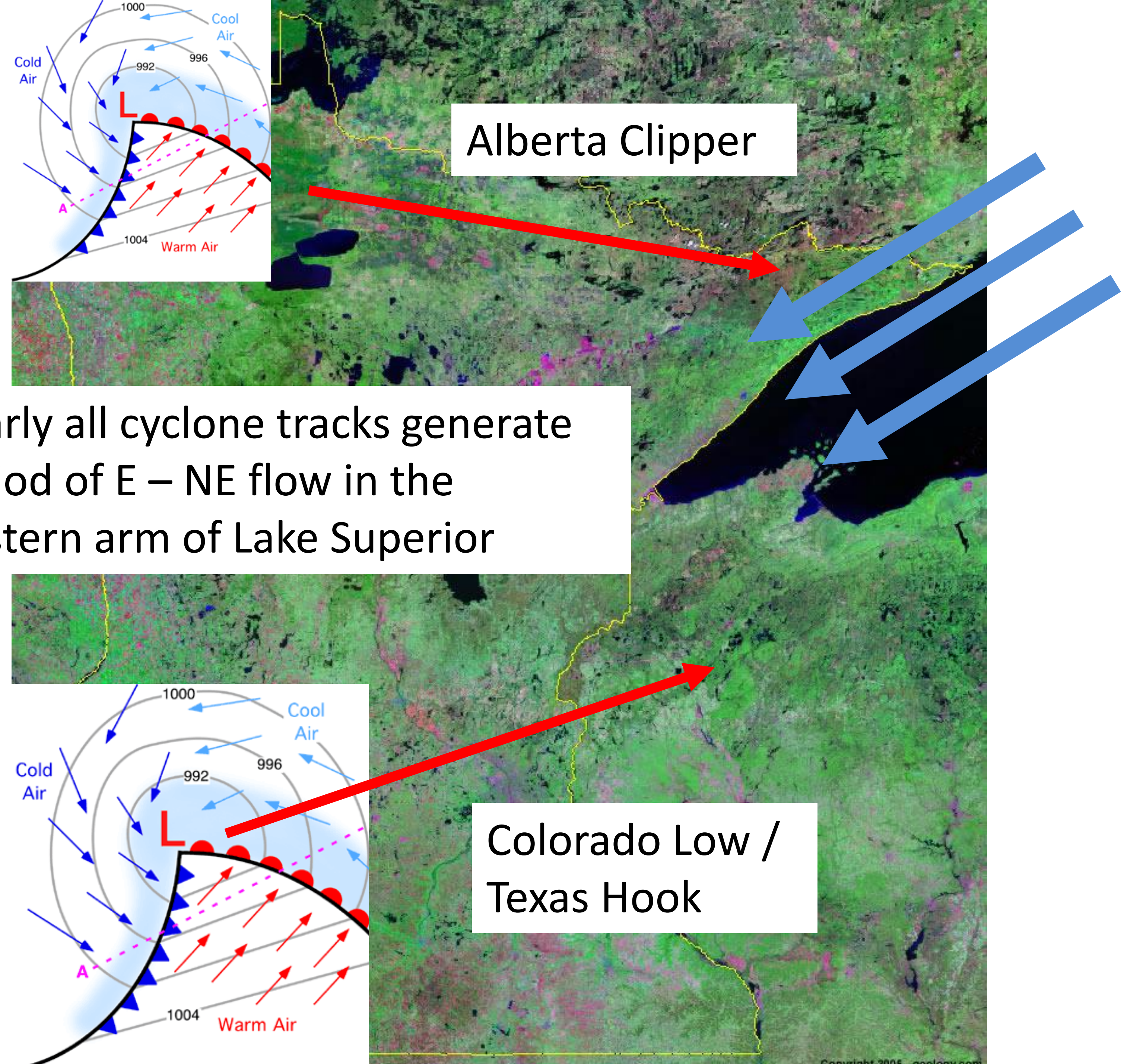
Coastal processes 101: Waves and **longshore transport**

Angled approach of wave crests to the shoreline sets up a **longshore current** of water and **SAND**

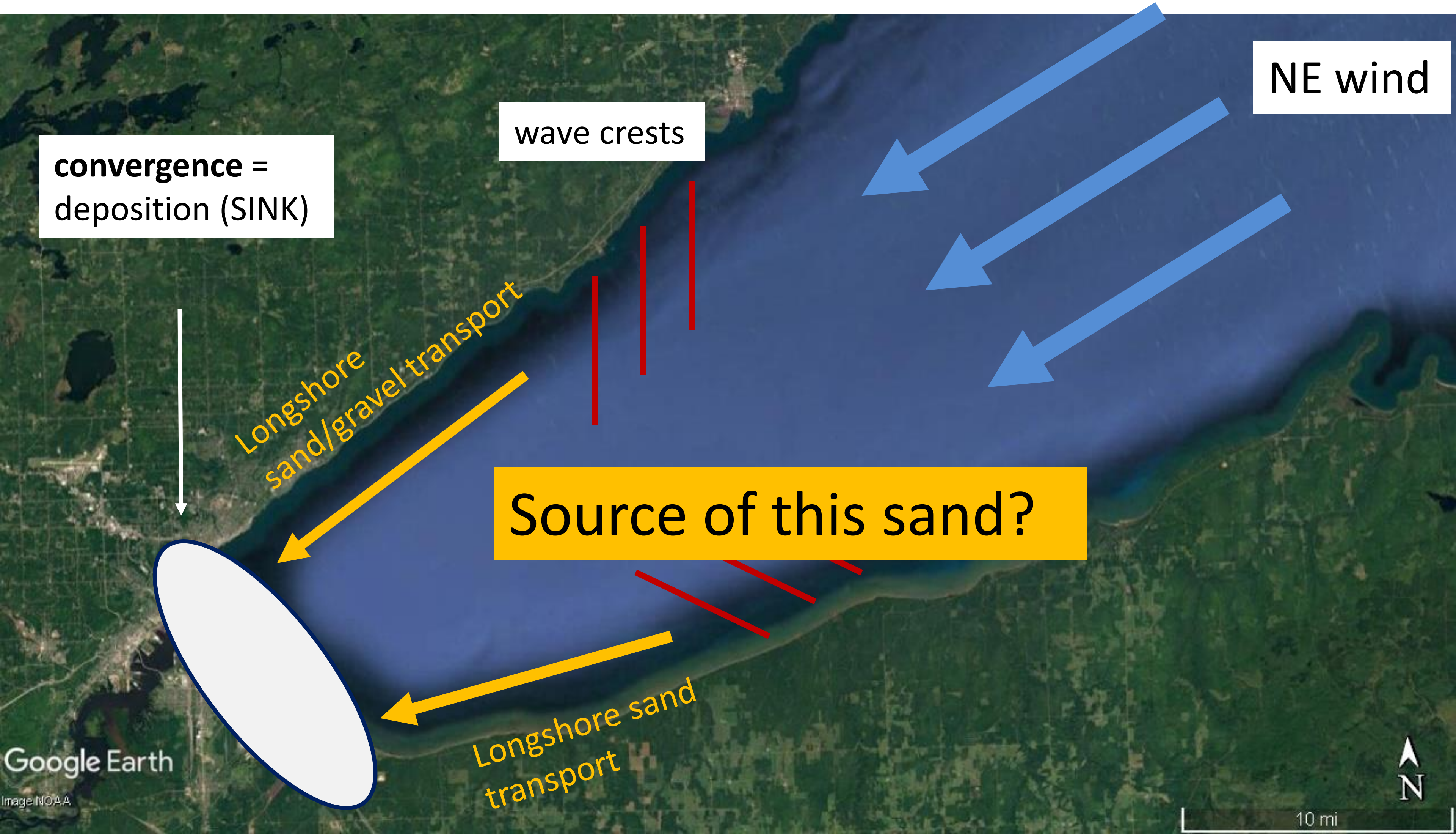
Longshore 'drift' (transport) = 'River of sand'



Nearly all cyclone tracks generate period of E – NE flow in the western arm of Lake Superior



Net **longshore transport** near Duluth



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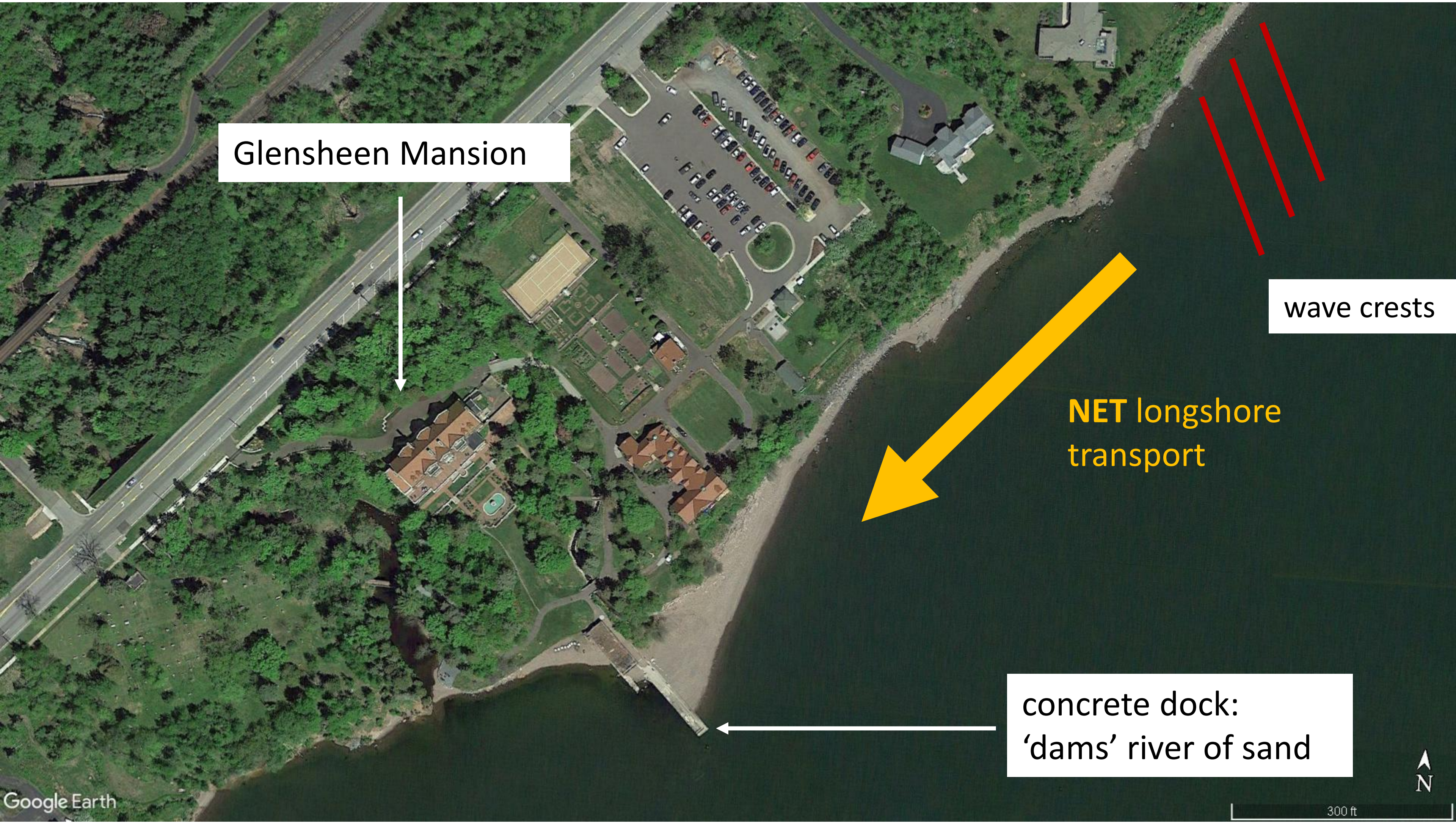
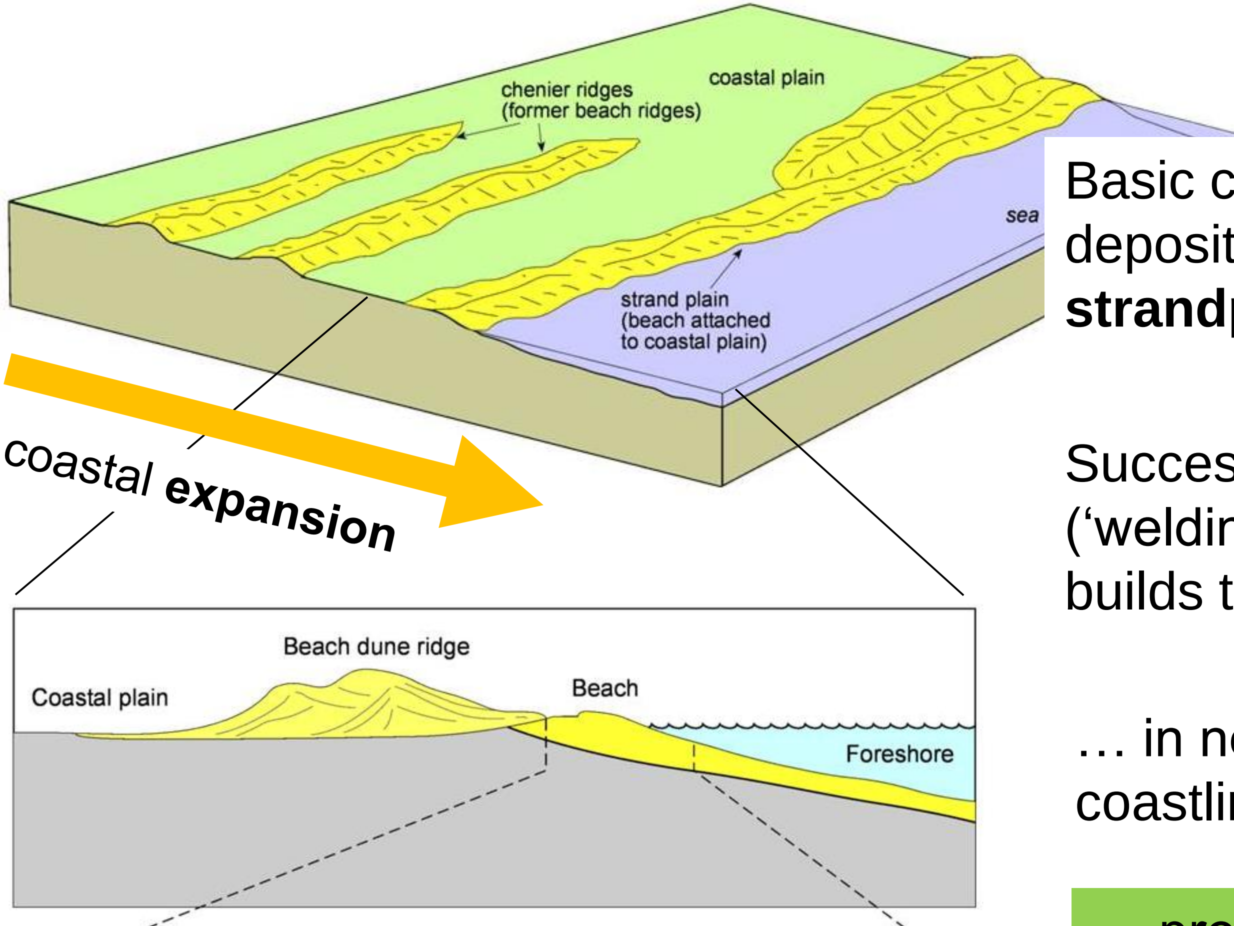


Coastal processes 101: Beaches and **Strandplains**



Basic constructional unit of a depositional coastline is a **strandplain**

Successive accretion ('welding on') of beach ridges builds the coastline lakeward

… in net **depositional** coastlines

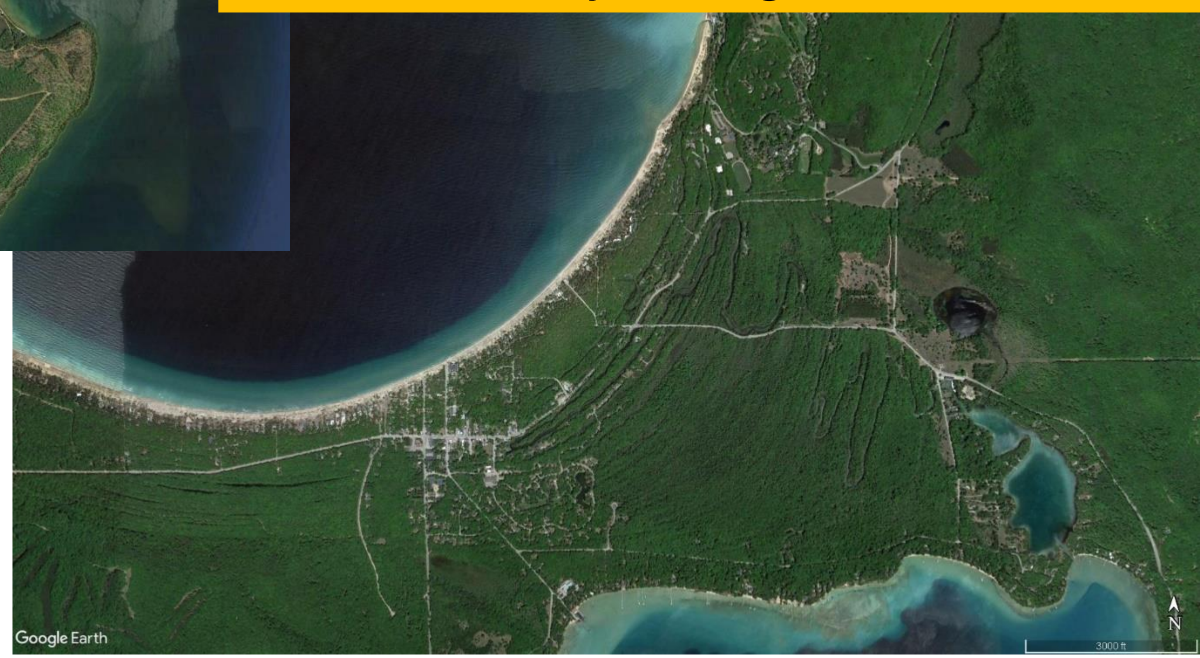
… provided lake level does not **rise** too quickly

Great Lakes **strandplains**

Grand Traverse Bay, east shore of Keweenaw Peninsula

Key Point: Strandplains form with **stable** or slowly **falling** lake level

Glen Arbor, MI (west of Traverse City, Leelanau Peninsula, Lake Michigan)



Long-term lake level change in Duluth area

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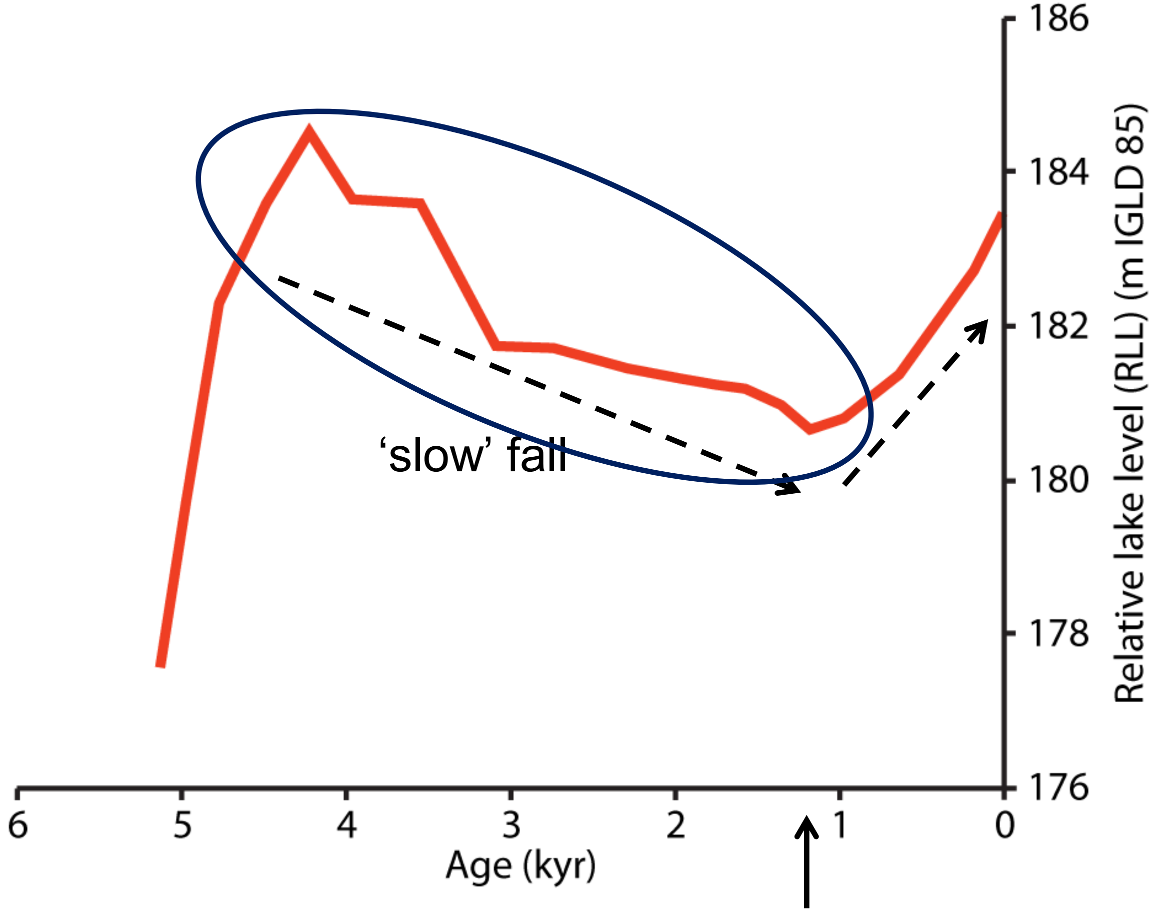
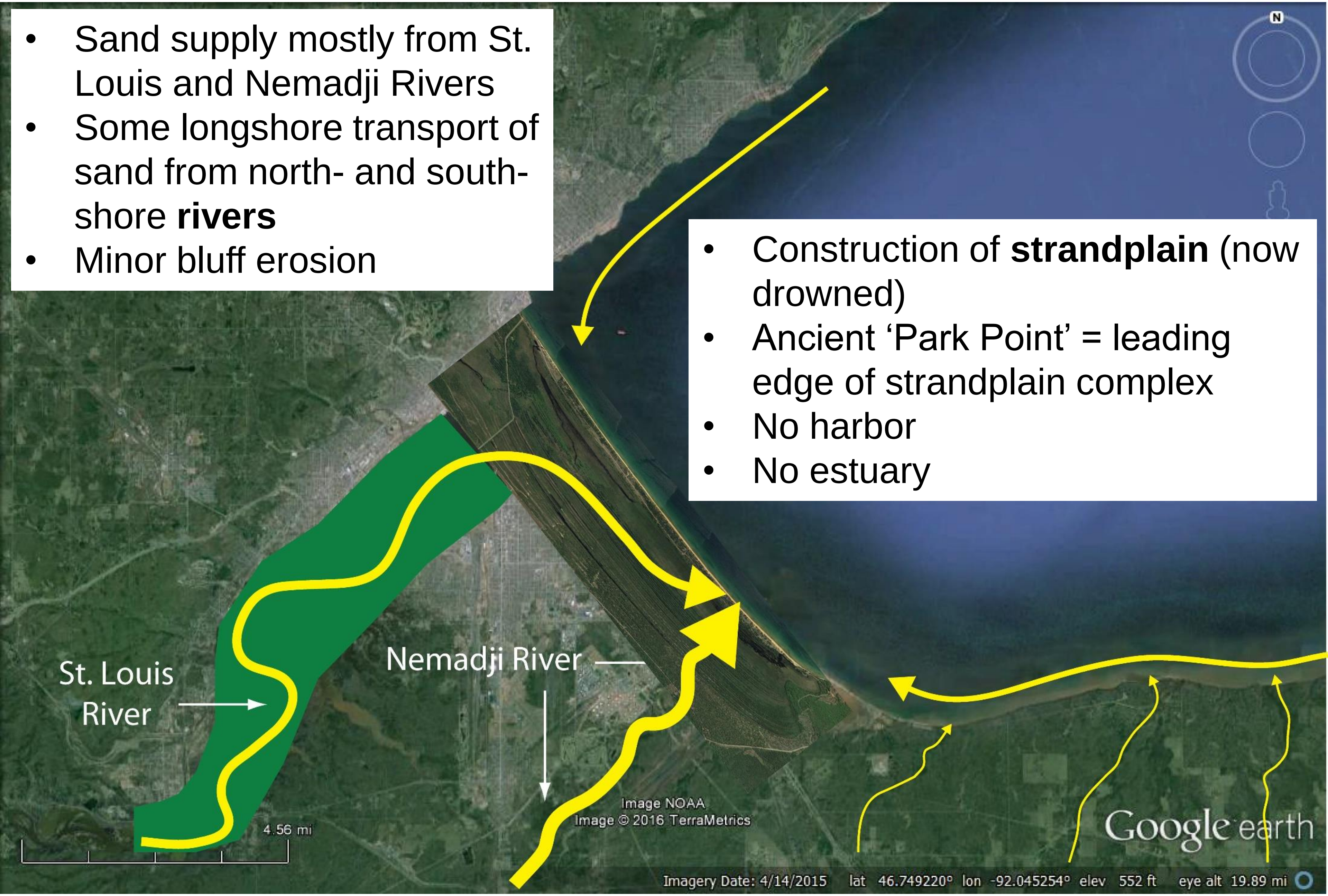


~ 1200 yr BP (+/- geologic slop)

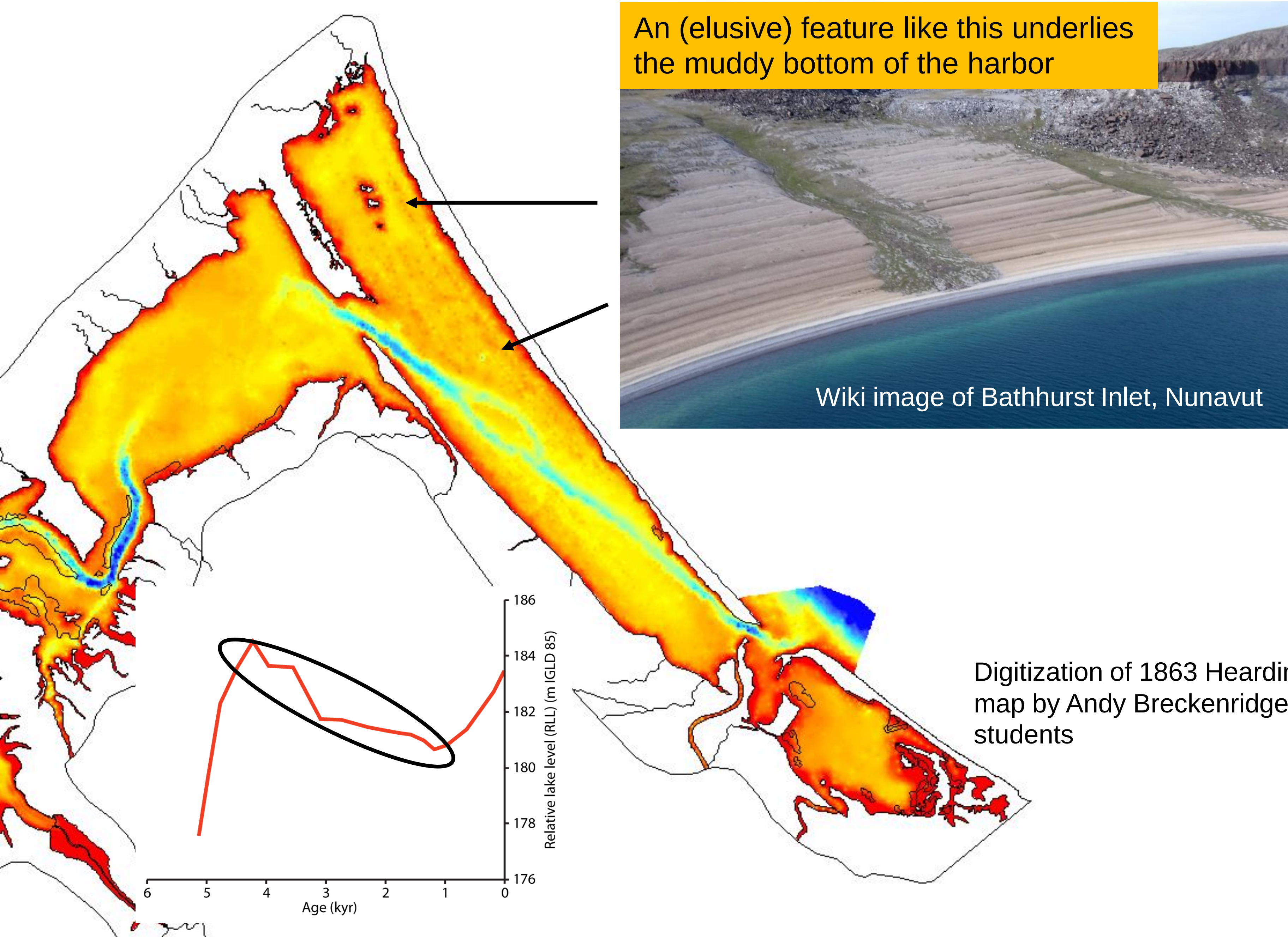
5000 – 1200 years BP: Slow lake-level **fall**

- Sand supply mostly from St. Louis and Nemadji Rivers
- Some longshore transport of sand from north- and south-shore **rivers**
- Minor bluff erosion

- Construction of **strandplain** (now drowned)
- Ancient 'Park Point' = leading edge of strandplain complex
- No harbor
- No estuary



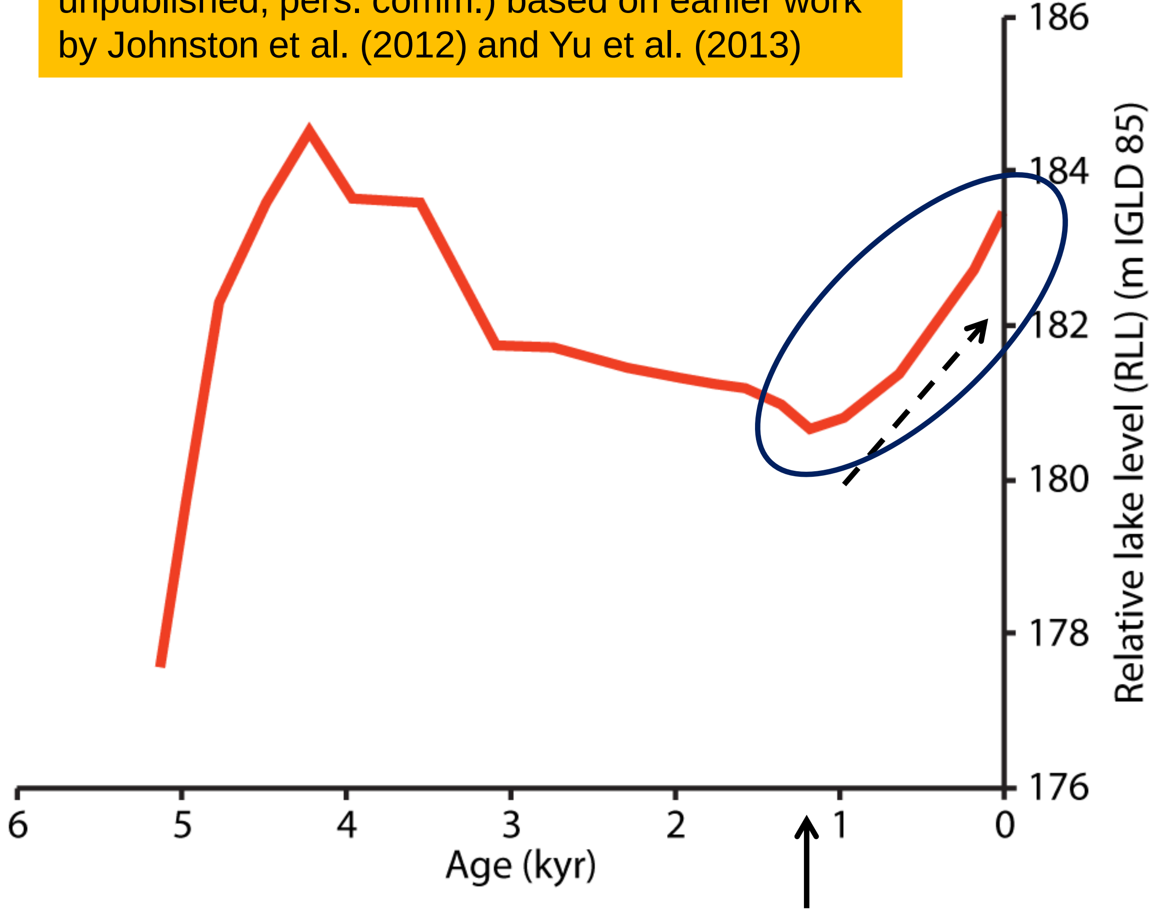
Supporting evidence for strandplain beneath harbor



Digitization of 1863 Hearding map by Andy Breckenridge and students

1200 years BP: Things change!

Lake-level curve by Andy Breckenridge (UWS; unpublished; pers. comm.) based on earlier work by Johnston et al. (2012) and Yu et al. (2013)



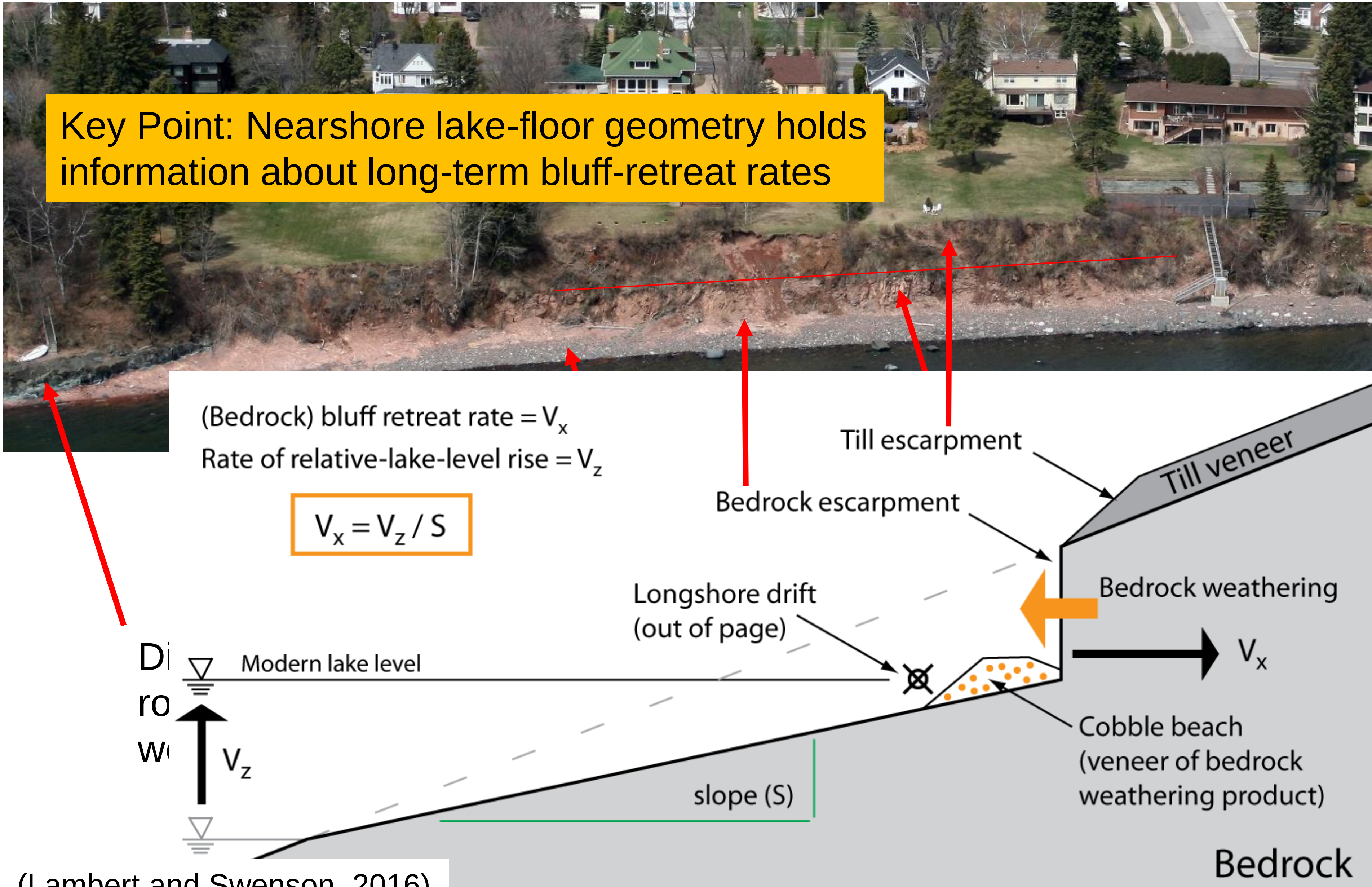
Change in outlet of Lake Superior @ ~ 1200 yr BP triggers **rise** in lake level

Rise rate ~ 2.5 – 3.0 mm/a in Duluth = FAST (geologically speaking)

~ 1200 yr BP (+/- geologic slop)

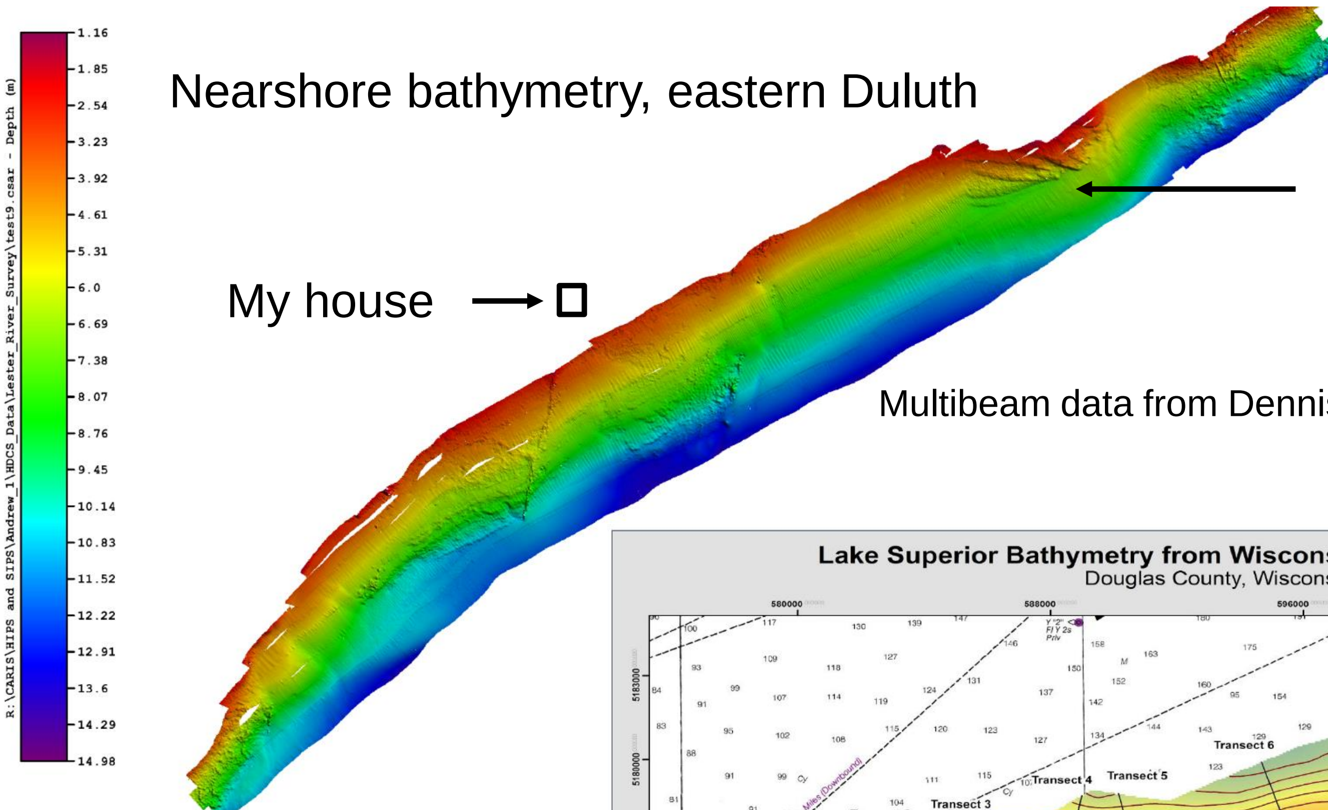
Rapid lake-level rise drives **bluff erosion**

Key Point: Nearshore lake-floor geometry holds information about long-term bluff-retreat rates



(Lambert and Swenson, 2016)

Long-term **bluff erosion** rates

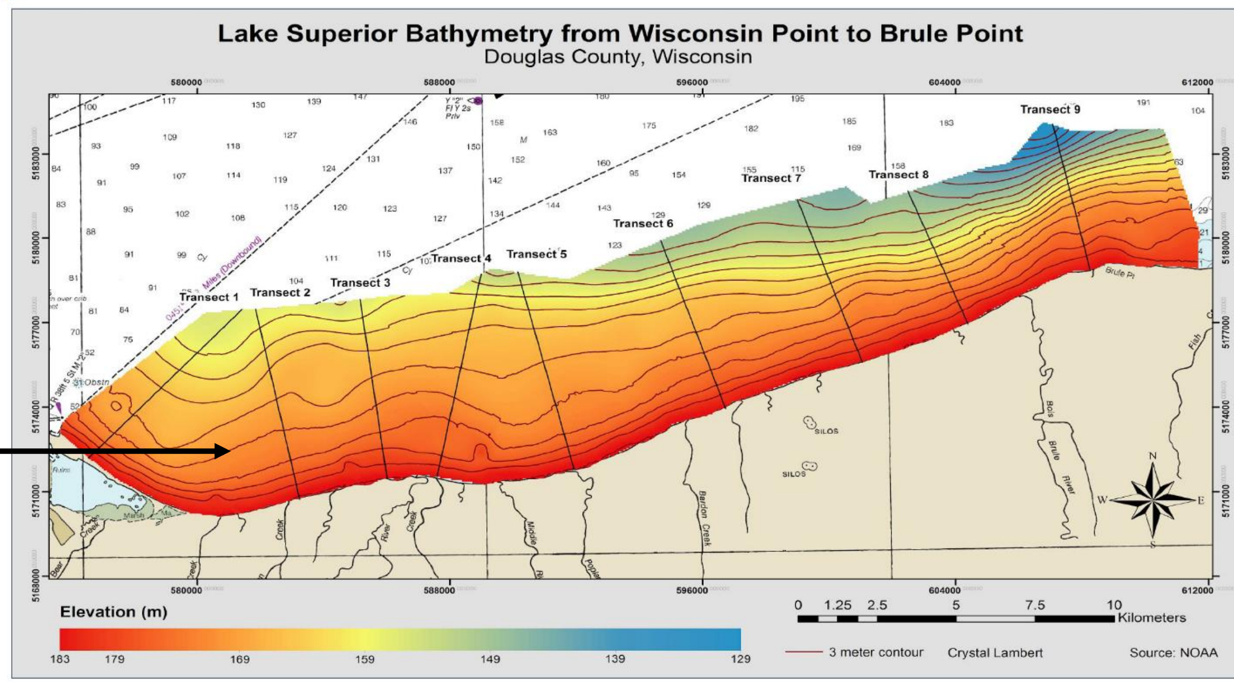


Nearshore bathymetry, eastern Duluth

My house

Lester River ‘delta’

Multibeam data from Dennison, Wattrus, & Swenson



Nearshore bathymetry east of Superior

Lambert and Swenson (2016)

Long-term **bluff erosion** rates

Label	Unit Name	Offshore Slope	Retreat Rate (cm/a)	Bluff
Mnb-1	Undifferentiated Mafic Lavas	0.049	5.145	N
Mnd	Leif Erikson Park Interflow	0.036	6.979	Y
Mes	Endion Sill	0.064	3.887	N
Mep	Endion granophyre	0.075	3.315	Y
Mnc	Congdon Park Rhyolite	0.060	4.200	Y
Mnn	Northland Basaltic Andesite	0.052	4.823	N
Mnu-1	Mafic Lavas - Lakeside	0.040	6.276	Y
Mne	40th Ave East Icelandite	0.035	7.211	Y
Mnr	42nd Ave East Rhyolite	0.050	4.964	Y
Mnu-2	Mafic Lavas - Lakeside	0.077	3.257	N
Mni-South	Lester Park Icelandite (buffered)	0.068	3.687	N
Mli	Lakeside Intrusion	0.085	2.940	Y
Mnu-3	Mafic Lavas - Lakeside	0.058	4.348	Y
Mni-North	Lester Park Icelandite	0.033	7.606	Y
Mnu-4	Mafic Lavas - Lakeside	0.047	5.271	N
Mna	Amity Creek Diabasic Basalt	0.043	5.811	N
Mnu-5	Mafic Lavas - Lakeside	0.052	4.846	N
Mmd	Lester River Sill	0.065	3.864	N
Mnb-2	North Shore Mafic Lavas	0.043	5.795	N
Srb	Sucker River Basalts	0.057	4.386	
Spd	Stony Point Diabase	0.100	2.500	
Mnb-4	Larsmont Basalts	0.070	3.560	

Lambert and Swenson (2016

Bedrock-cored north-shore bluff retreat rate ~ **4** cm/yr

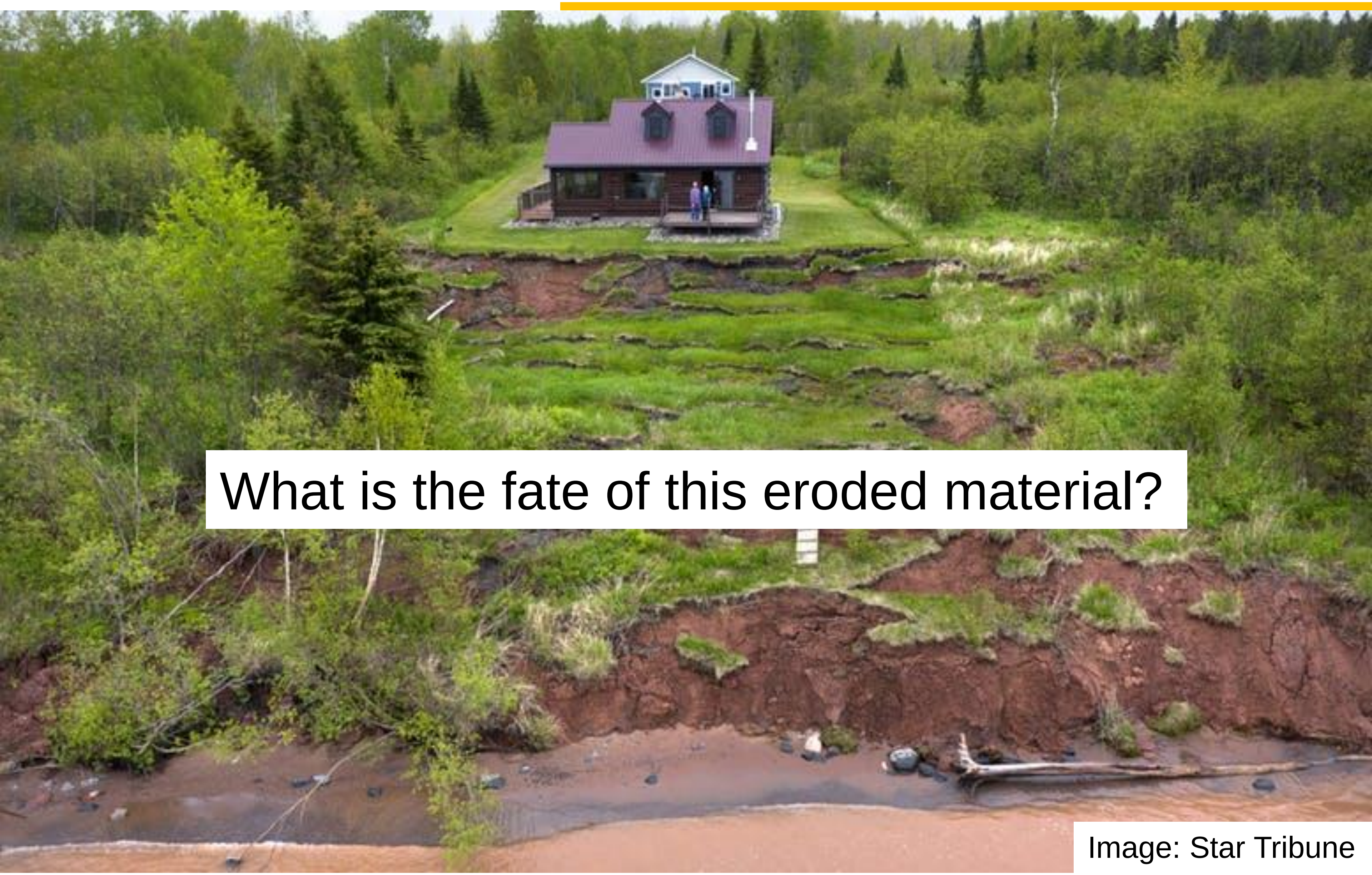
Large variability because of mixed lithology, e.g. rhyolite vs. basalt vs. diabase

Line	Offshore slope	Retreat Rate (cm/a)
Transect 1	0.0049	51
Transect 2	0.0048	52
Transect 3	0.0039	64
Transect 4	0.0041	61
Transect 5	0.0055	45
Transect 6	0.0061	41
Transect 7	0.0059	42
Transect 8	0.0068	37
Transect 9	0.0077	33

South-shore bluff retreat rate ~ **40** cm/yr

Mechanically weak, unconsolidated till

Less variability -> homogenous till



What is the fate of this eroded material?

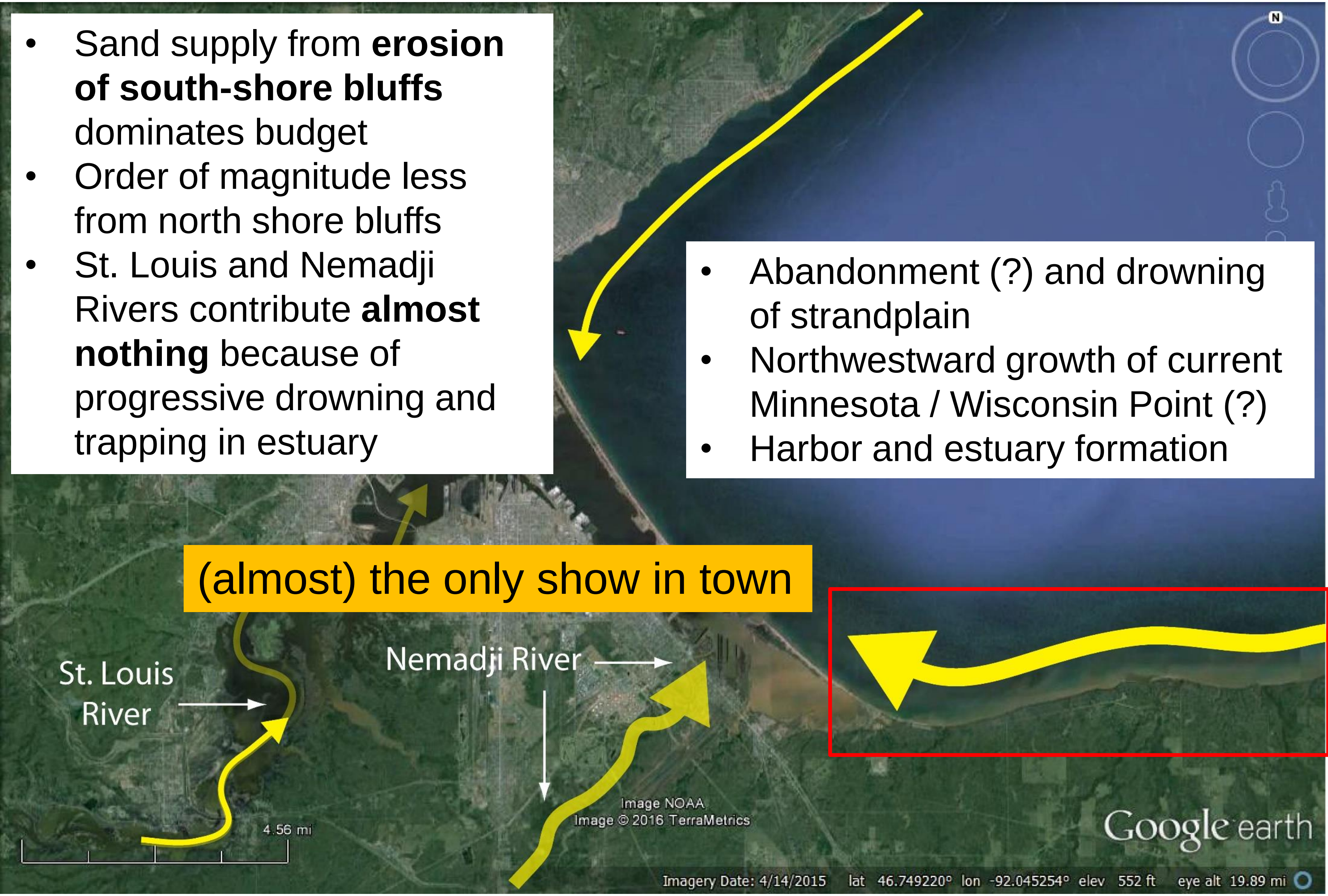
Image: Star Tribune

1200 years BP - **modern**: Rapid lake-level **rise**

- Sand supply from **erosion of south-shore bluffs** dominates budget
- Order of magnitude less from north shore bluffs
- St. Louis and Nemadji Rivers contribute **almost nothing** because of progressive drowning and trapping in estuary

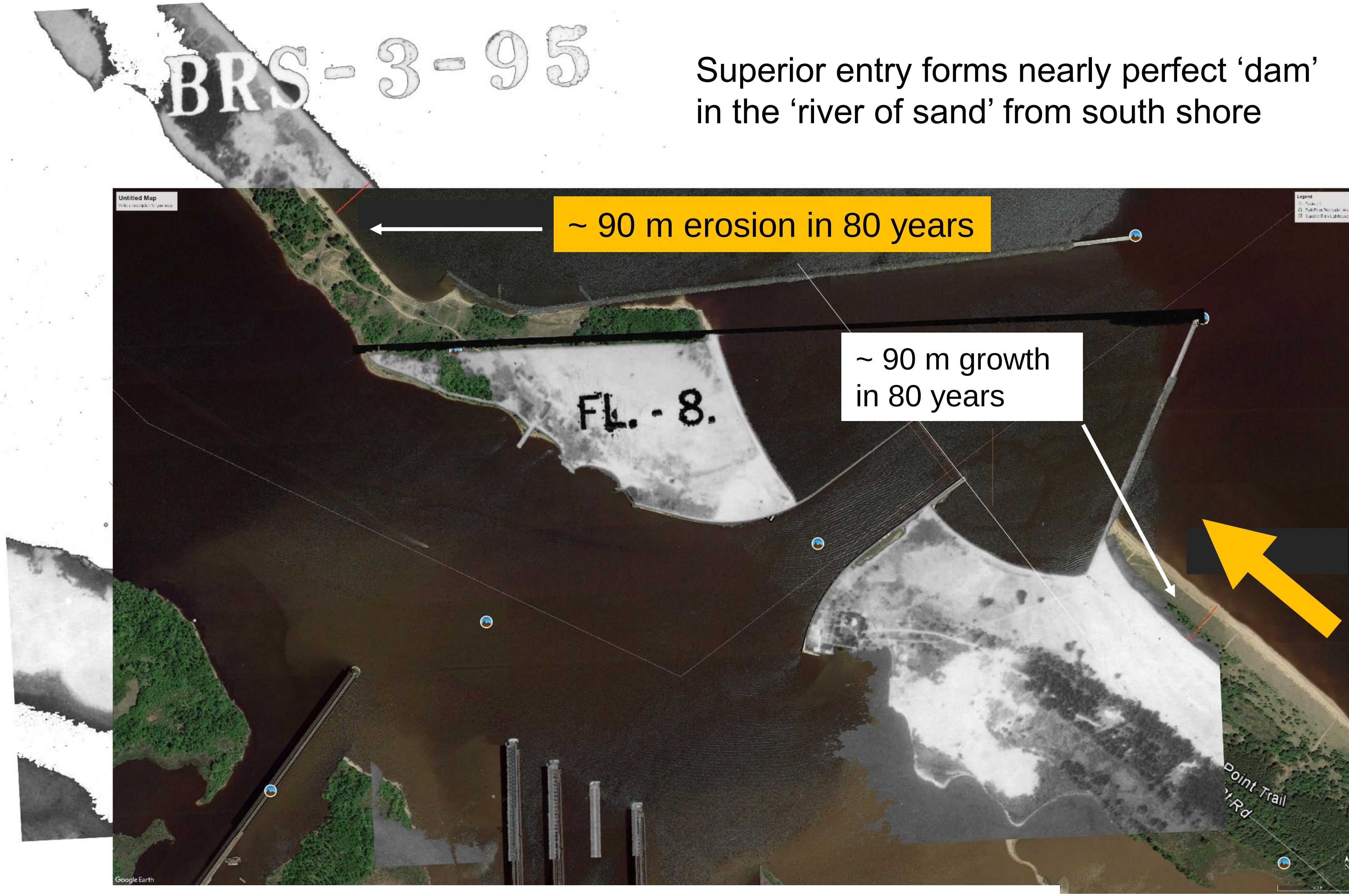
- Abandonment (?) and drowning of strandplain
- Northwestward growth of current Minnesota / Wisconsin Point (?)
- Harbor and estuary formation

(almost) the only show in town



The ‘infrastructure’ problem: **Starvation**

Superior entry forms nearly perfect ‘dam’ in the ‘river of sand’ from south shore



Overlay of 2017 (color) satellite image and 1938 aerial photo.

The ‘infrastructure’ problem: Starvation

Similar story with the Duluth breakwater

Blocks sediment supply from north-shore bluff erosion

But sediment supply from north shore is significantly smaller

The ‘infrastructure’ problem: **Starvation**

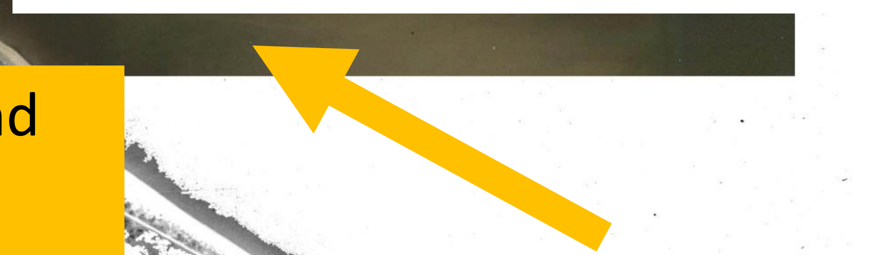
Sand budget:

35,000 – 45,000 m^3/yr sand

(2001 Corps estimate ~ 50,000 m^3/yr sand)

Bluff erosion alone can close sand budget (little river input):

35 km of bluff x 10% sand x 40 cm/yr retreat rate x 30 m total bluff height = 40,000 m^3/yr sand



Where might we find the necessary sand volume to **nourish** Minnesota Point downstream of the Superior entry?

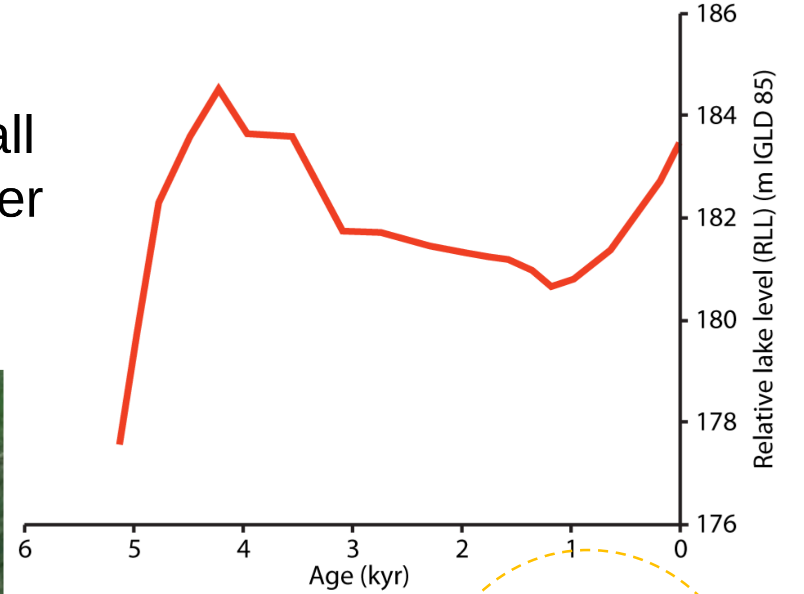
Modern sand sources: What about the **St. Louis River**?

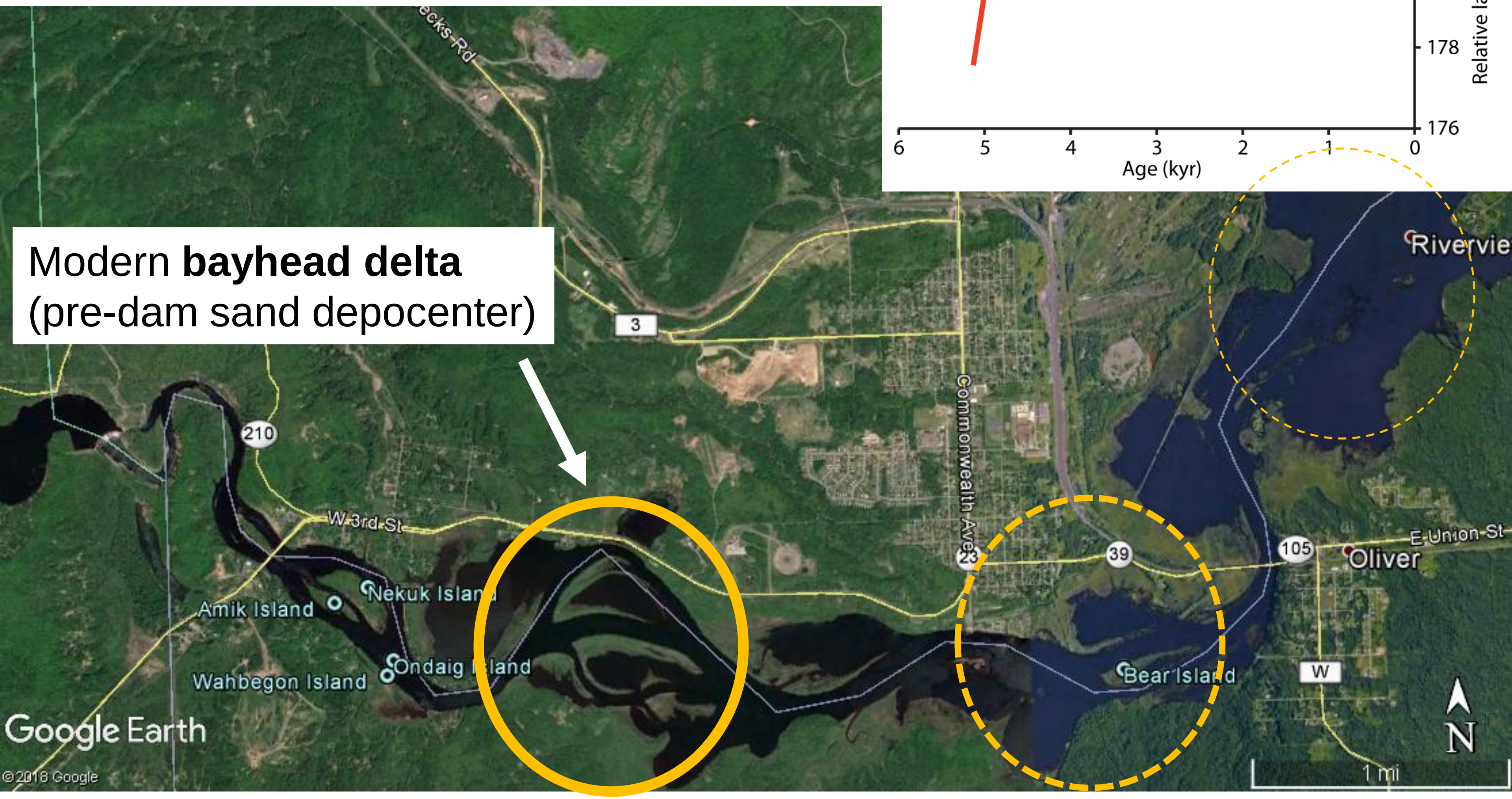
Note progressive drowning of **RELICT** (inactive) **SAND** levees over 160-year timespan

Little sand was reaching Spirit Lake in 1860 (pre-dam era)

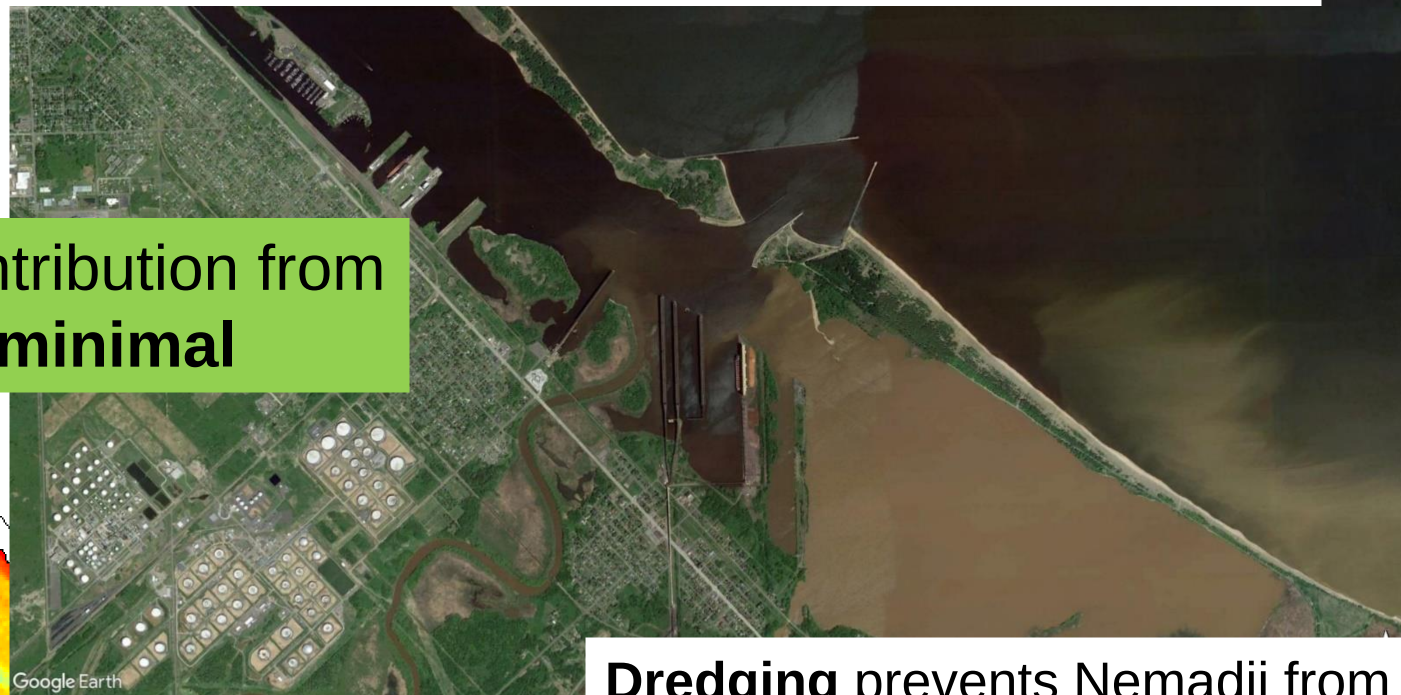
Where was it deposited?

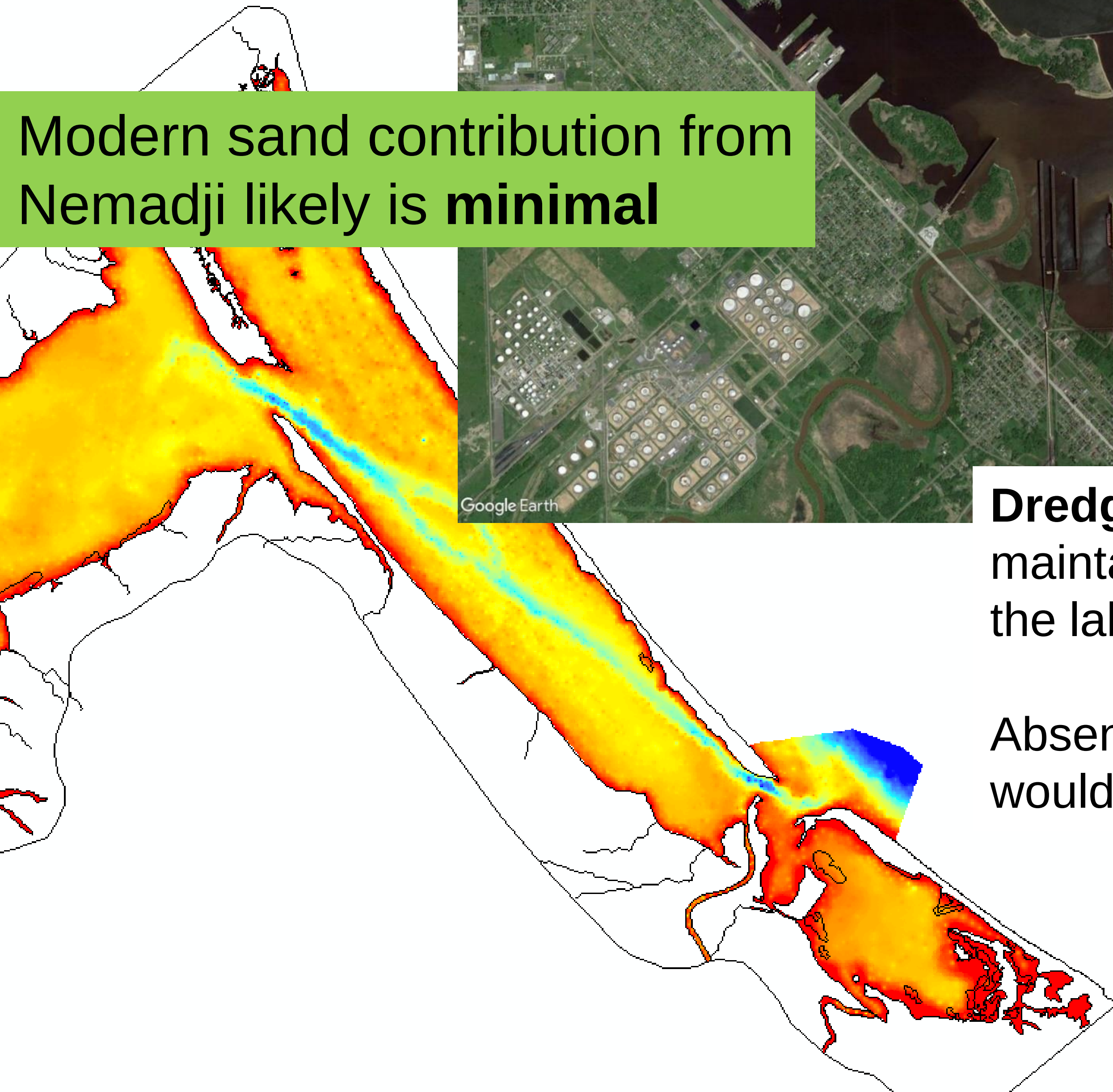
- St. Louis could deliver sand to lake (strandplain) during 4.5 – 1.2 kyr BP RLL fall
- Onset of RLL rise at 1.2 kyr BP drowned river mouth and drove depocenter 'upstream'
- Last position (pre-dam) was Fond du Lac





Modern sand sources: What about the **Nemadji River**?





Modern sand contribution from Nemadji likely is **minimal**

Dredging prevents Nemadji from maintaining **weak connection** to the lake side of the barrier

Absent dredging, Nemadji outlet would drown naturally, as well

Modern sand sources: What about the **Nemadji River**?

Erosion and Sedimentation
in the
Nemadji River Basin

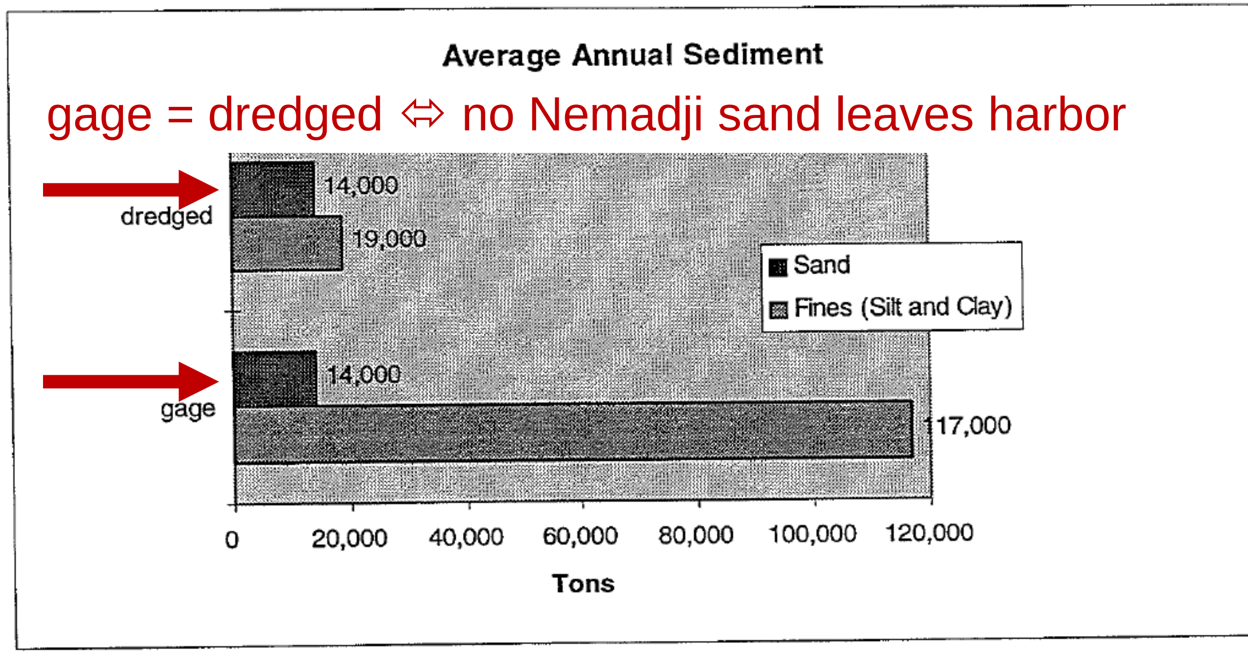
Nemadji River Basin Project Final Report

Natural Resources Conservation Service

U.S. Forest Service

January, 1998
2nd printing, July, 1998
3rd printing, June, 1999

Figure 18: Comparison of Sediment Measured at Gage and Sediment Dredged



Take-home message:

All sand trapped in harbor (and then dredged)

Significant mud transfer to lake (visual confirmation)

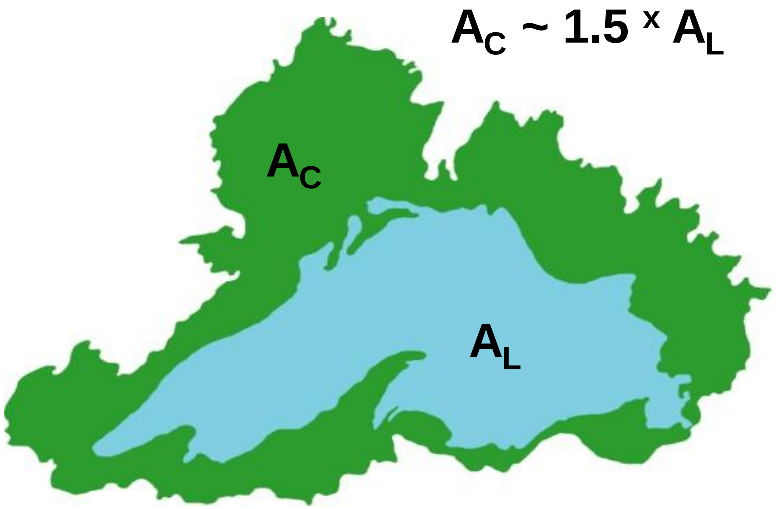
14,000 tons/yr ~ 6300 m^3/yr

Small fraction of 35,000 – 50,000 m^3/yr needed

The ‘**climate change**’ problem: **Drowned** and battered

How might climate change affect Minnesota Point?

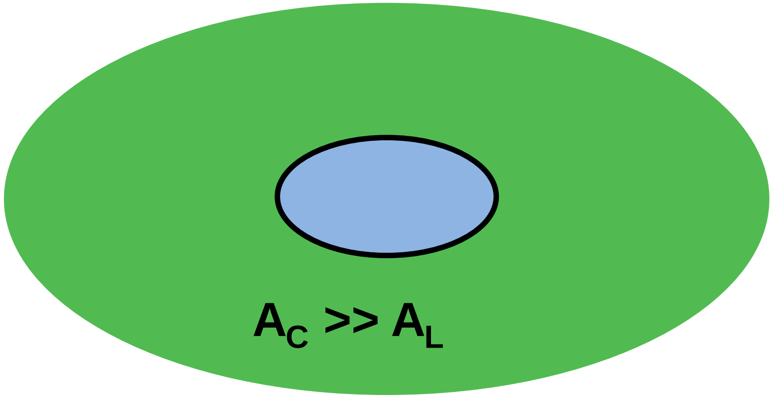
- Most climate models predict increased **precipitation** and temperature (‘warmer & wetter’)
- Perturb hydrologic budget
- Increased **runoff** and **lake level**



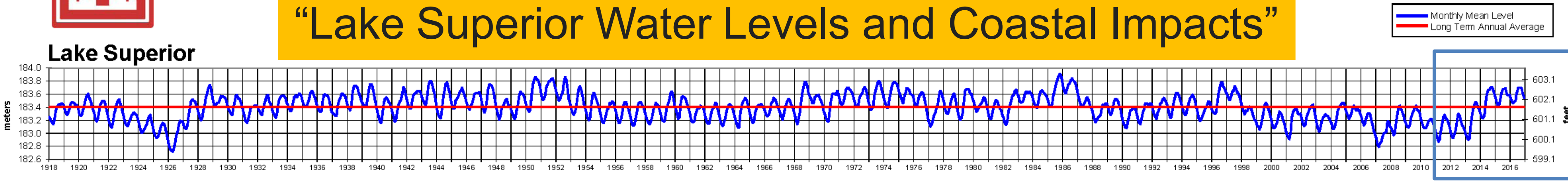
Lake Superior:

- Small ratio of catchment (A_c) to surface area (A_c)
- Somewhat **less sensitive** to runoff changes (?)

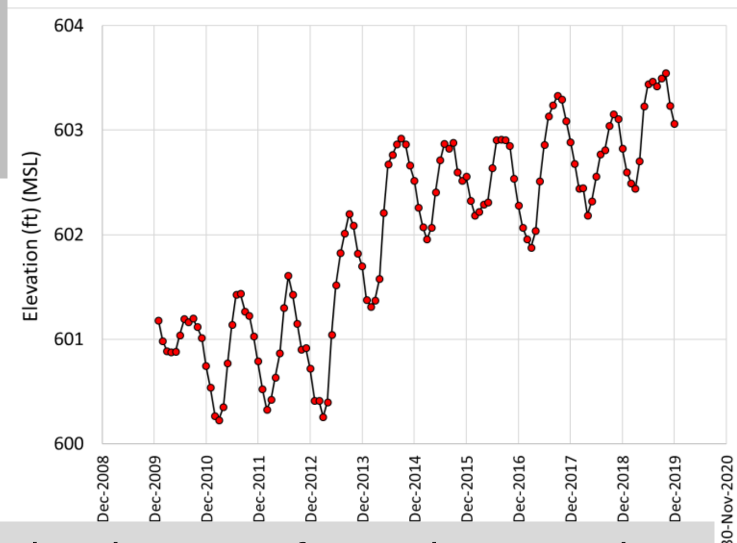
‘Typical’ lake



Next TPCC talk (April 21, online format)
Brandon Krumwiede
“Lake Superior Water Levels and Coastal Impacts”



Quasi-decadal cycles:
∆ Lake level ~ 60 – 80 cm
Driver: Fluctuations in atmospheric circulation
Might be changing flavor…



AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2013GL058679

Key Points:
- A climatically driven decadal oscillation dominates the regional water cycle
- The oscillation is governed by ($P - E$) and a stage-dependent runoff flux
- A recent change in oscillation may mark the onset of a new hydroclimatic regime

Supporting Information:
- Readme
- Relationship between total evaporation (May-November) and summer evaporation (June, July and August) for the in-lake evaporation pan.
- Spectral analysis (FFT) of the time-series for: annual water level (A), annual change in water level (B), annual precipitation minus evaporation (C), annual precipitation (D), annual evaporation (E), annual water level pre-1998 (F), annual water level post-1998 (G) in the NHLD. (data detrended; cs2Hann window; PSD SSA: power spectral density as sum squared amplitude) Horizontal lines indicate the 50% (yellow), 90% (green), 95% (blue) and 99% (red) significance levels (white noise

Decadal oscillation of lakes and aquifers in the upper Great Lakes region of North America: Hydroclimatic implications

C. J. Watras[1,2], J. S. Read[3], K. D. Holman[4], Z. Liu[5,6], Y.-Y. Song[6], A. J. Watras[7], S. Morgan[8], and E. H. Stanley[2]

[1]Wisconsin Department of Natural Resources, University of Wisconsin-Madison Trout Lake Research Station, Boulder Junction, Wisconsin, USA, [2]Center for Limnology, University of Wisconsin-Madison, Madison, W Integrated Data Analytics, U.S. Geological Survey, Middleton, Wisconsin, USA, [4]Center for Clima Wisconsin-Madison, Madison, Wisconsin, USA, [5]Department of Atmospheric and Oceanic Scien Research, University of Wisconsin-Madison, Madison, Wisconsin, USA, [6]Department of Atmospl Peking University, Beijing, China, [7]Department of Electrical and Computer Engineering, Univers Madison, Wisconsin, USA, [8]Wisconsin Valley Improvement Company, Wausau, Wisconsin, USA

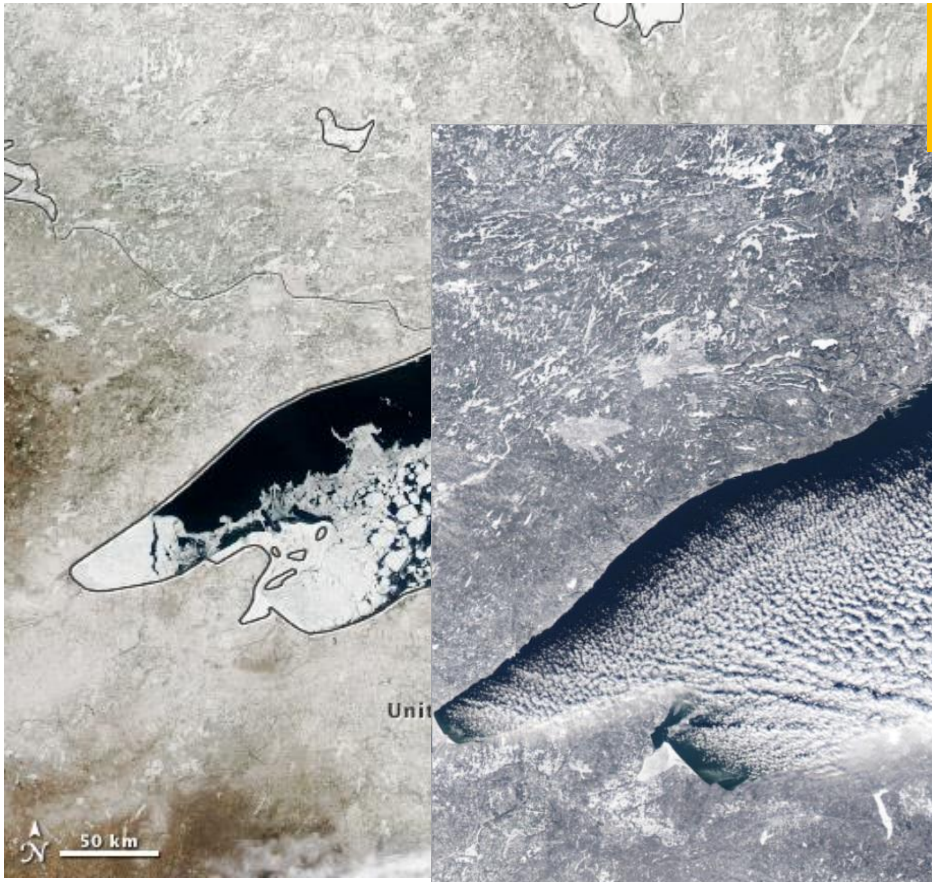
Abstract We report a unique hydrologic time series which indicates that water lev across the upper Great Lakes region of North America have been dominated by a c near-decadal oscillation for at least 70 years. The historical oscillation (~13 years) is rema small seepage lakes, groundwater tables, and the two largest Laurentian Great Lakes d differences in hydrology. Hydrologic analyses indicate that the oscillation has been gov changes in the net atmospheric flux of water ($P - E$) and stage-dependent outflow. Th hypothetically connected to large-scale atmospheric circulation patterns originating in Pacific that support the flux of moisture into the region from the Gulf of Mexico. Recent c change in the historical oscillation characterized by an ~12 years downward trend begin water levels region wide may mark the onset of a new hydroclimatic regime.

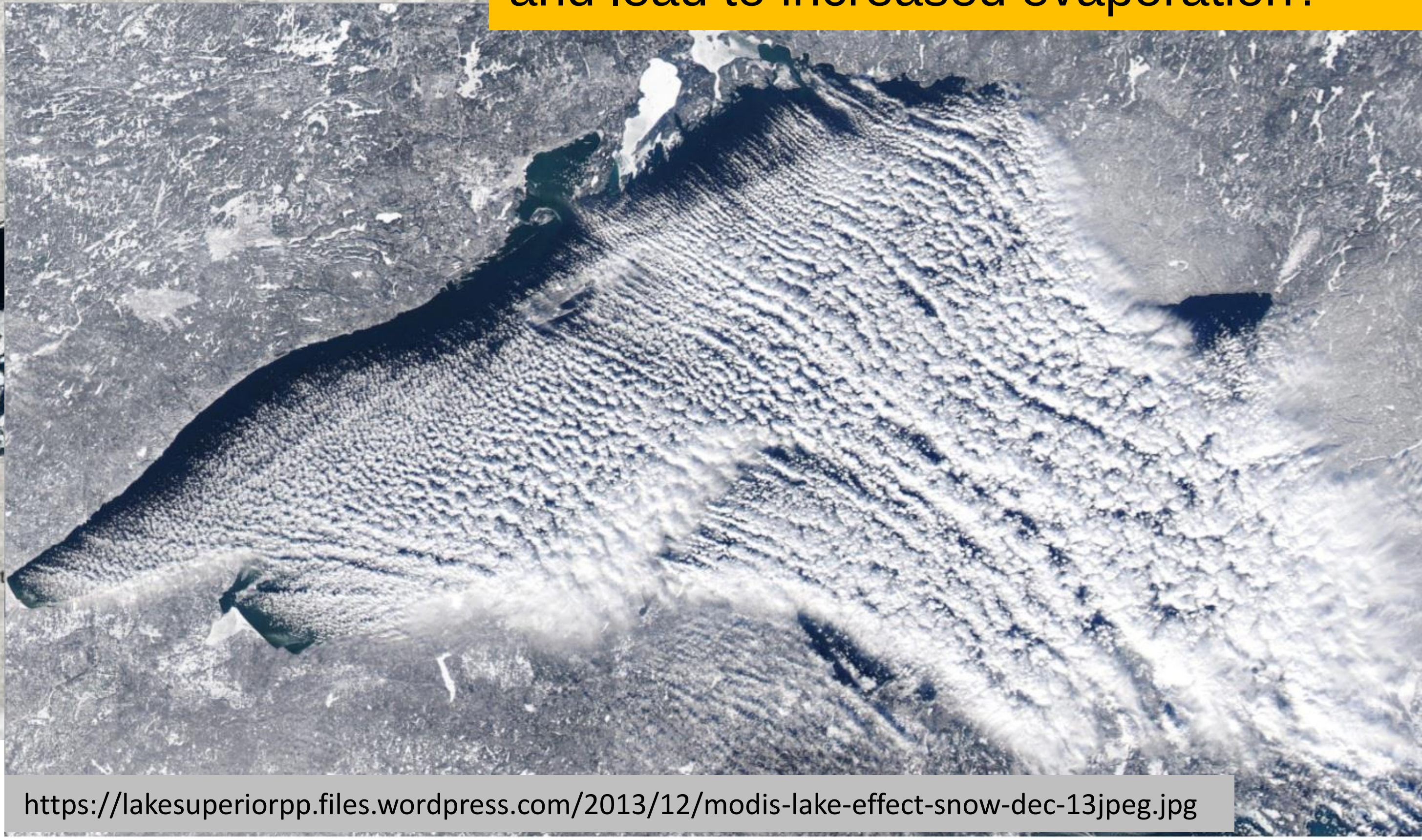
*"NOAA National Centers for Environmental Information reports that the 12 months ending in January of 2020 is the **wettest 12-month period** on record in the Great Lakes basin. Moreover, the 60 months ending in January 2020 was the **wettest 60-month period** on record in the basin."*

The ‘**climate change**’ problem: **Drowned** and battered

How might climate change affect Minnesota Point?

‘Winter’ evaporation extremely important…





Will a warmer climate reduce ice cover and lead to increased evaporation?

https://lakesuperiorpp.files.wordpress.com/2013/12/modis-lake-effect-snow-dec-13jpeg.jpg

The ‘**climate change**’ problem: Drowned and **battered**

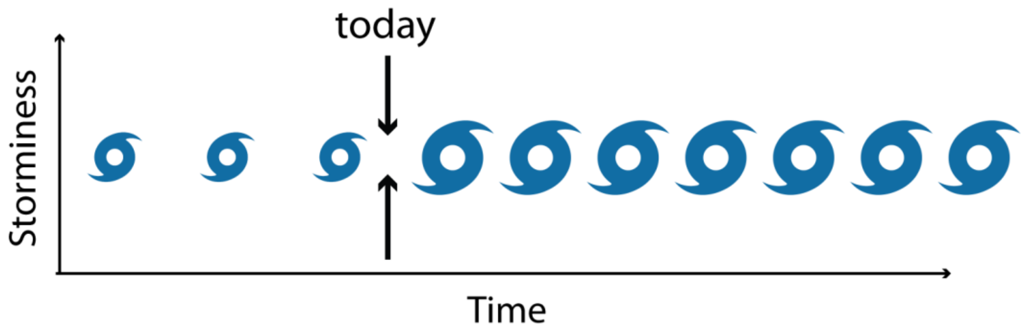
How might climate change affect Minnesota Point?

Potential for **increased frequency** and/or **magnitude** of mid-latitude **cyclones** and associated **wind/wave** field

Increased **efficiency** (diffusivity) of **longshore transport**

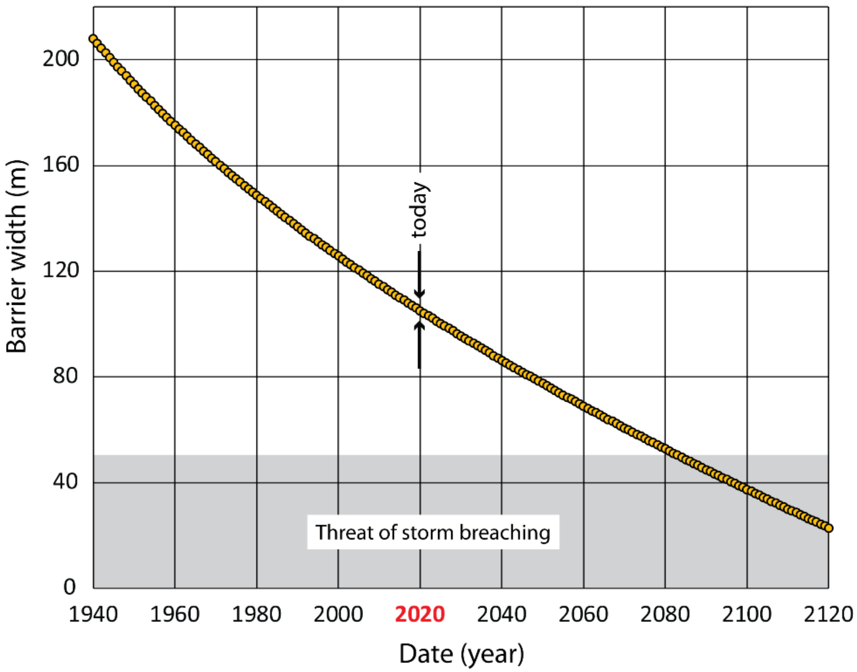
Rapid morphodynamic response of barrier

- Modeled barrier (MN/WI points) response to climate change
- Developed simple morphodynamic model of longshore transport and barrier response
- Focused on Superior entry
- Imposed change in transport efficiency (‘climate’ proxy)



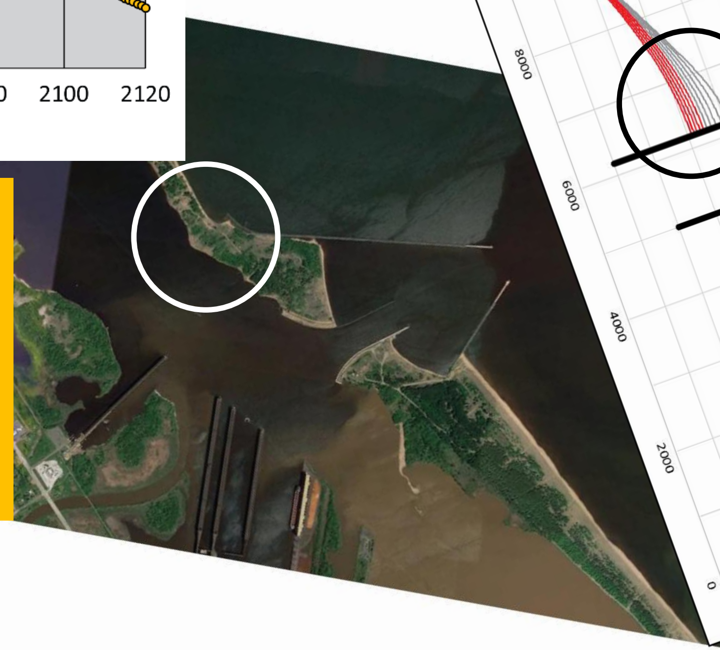
The ‘**climate change**’ problem: Drowned and **battered**

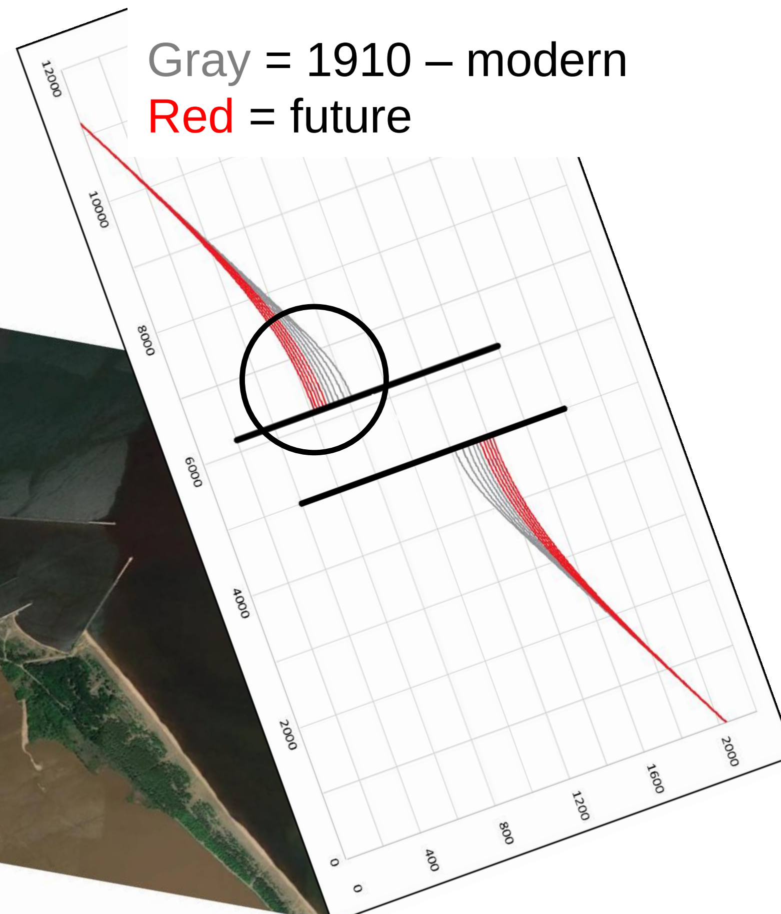
Very preliminary morphodynamic model predictions



Beach profiles: 1910 – 2120 (20-year increments)

Gray = 1910 – modern
Red = future

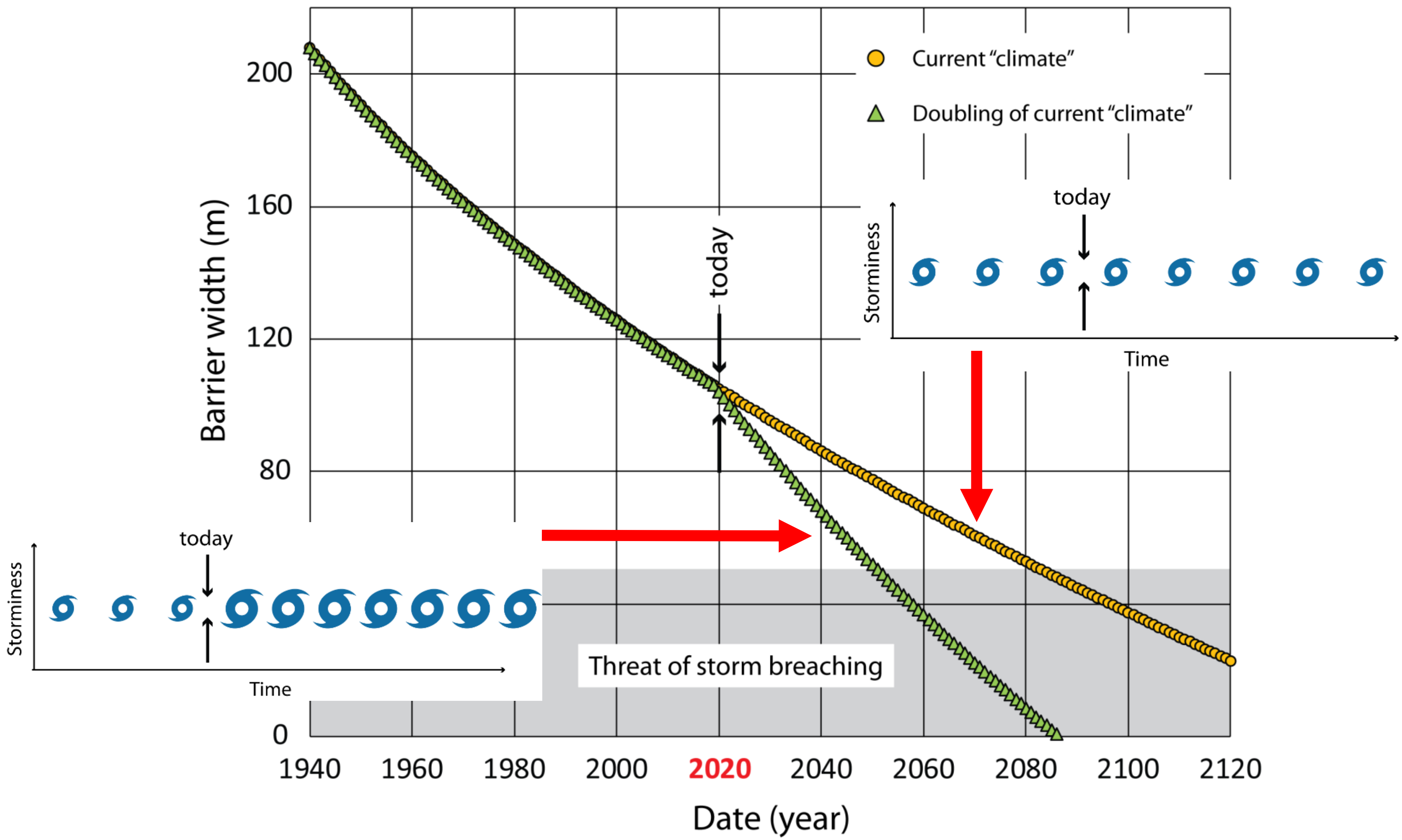




Under current climate regime, barrier vulnerable to **breaching** within a **century** (very conservative estimate—likely sooner)

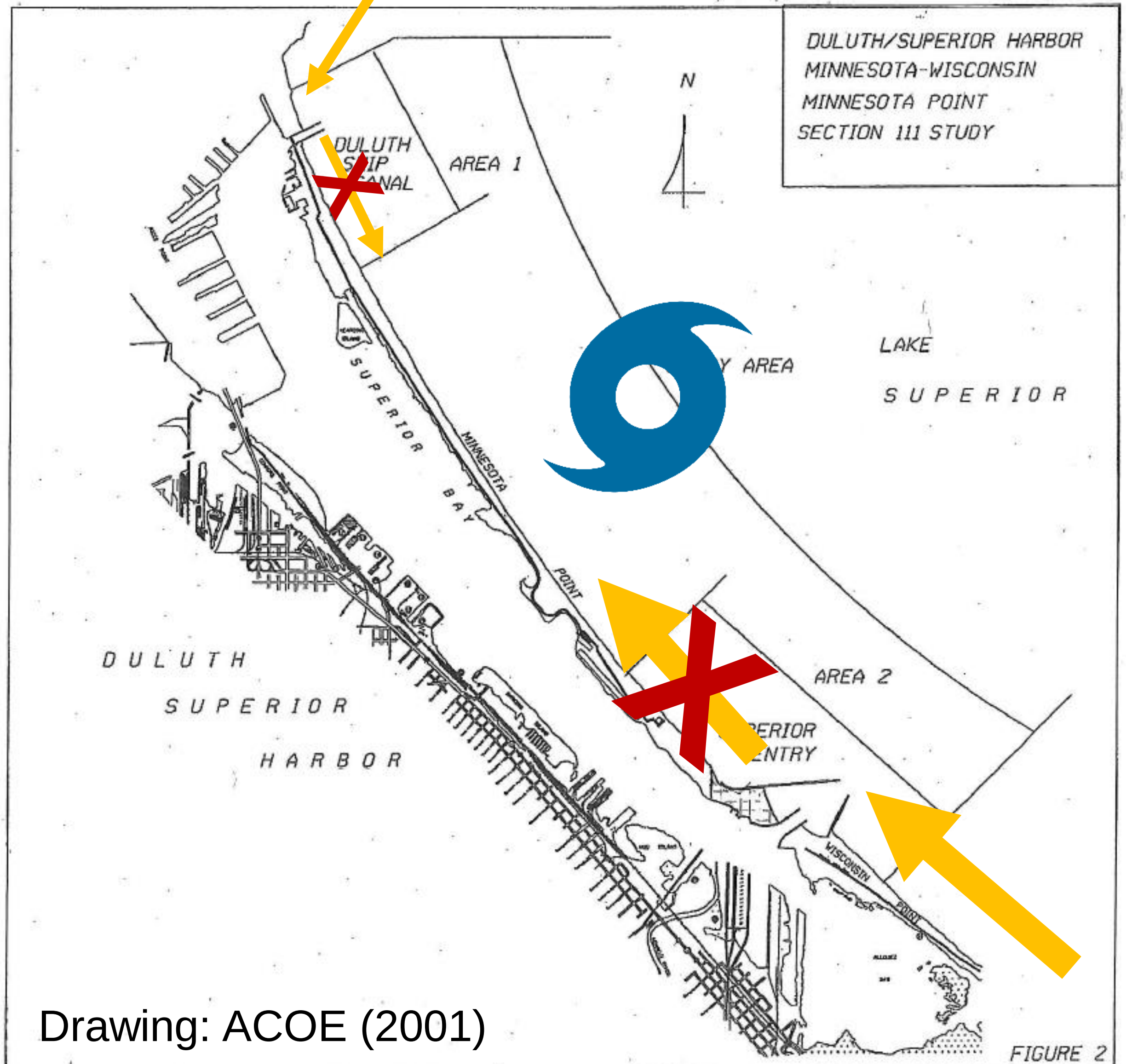
The ‘**climate change**’ problem: Drowned and **battered**

Doubling of ‘climate’ (increasing frequency and magnitude of cyclones)



Final thoughts

For their size, barrier islands are the most **dynamic** / **ephemeral** landforms on Earth



Drawing: ACOE (2001)

Drowned:
Sea level rise & sediment compaction (subsidence)

Drowned:
Post-glacial lake level rise

Starved:
Trapping of sand supply behind upstream dams

Starved:
Trapping of sand supply
behind breakwaters

Battered:
Increasing frequency and magnitude of tropical cyclones

Battered:
Increasing frequency and
magnitude of mid-latitude cyclones

s of barrier systems
e is no recovery

Questions?

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